Mixed Reality Interiors: Exploring Augmented Reality Immersive Space Planning

Design Archetypes for the Creation of Interior Spatial Volume 3D User Interfaces

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Abstract

Mixed Reality Interiors: Exploring Augmented Reality Immersive Space Planning Design Archetypes for the Creation of Interior Spatial Volume 3D User Interfaces

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Augmented reality is an increasingly relevant medium of interaction and media reception with the advances in user worn or hand-held input/output technologies endowing perception of the digital nested within and reactive to the native physical. Our interior spaces are becoming the media interface and this emergence affords designers the opportunity to delve further into crafting an aesthetics for the medium.

Beyond having the virtual assets and applications in correct registration with the real-world environment, critical topics are addressed such as the compositional roles of virtual and physical design features including their purpose, modulation, interaction potentials and implementation into varying indoor settings. Examining and formulating methodologies for mixed reality interior 3D UI schemes derived from the convergence of digital media and interior design disciplines comprise the scope of this design research endeavor.

A holistic approach is investigated to produce a framework for augmented reality 3D user interface interiors through research and development of pattern language systems for the balanced blending of complimentary digital and physical design elements. These foundational attributes serve in the creation, organization and exploration of interactive possibilities and implications of these hybrid futuristic spatial interface layouts.

1. INTRODUCTION + BACKGROUND AND LITERATURE SURVEY

1.1 Research Question

How can digital media and interior design principles of construction be combined to formulate a 3D user interface space planning and interactivity aesthetics for mixed augmented reality interior spatial compositions?

1.1.1 Essential Definitions

Mixed Reality – This is a catchall umbrella term referring to the blend of real world with virtual digital elements to generate a range of interactive experiences. Mixed reality in accordance to the windows platform definition exists on a spectrum inclusive of Augmented reality and Virtual Reality both at opposite ends including gradients in between. [31]

For clarity's sake, this research endeavor will primarily be focusing on development in the Augmented reality zone of the Mixed reality spectrum though some of the methodologies and concepts are translatable throughout the gradients of the spectrum some of which include VR.

1.1.2 Introduction

I am investigating the design and transformation of future interiors into fully immersive Mixed Augmented Reality Computer Interfaces. I aim to explore the design pattern languages derived from the cross disciplinary approach into media/interior design that can be utilized to effectively craft 3D user interfaces for everyday use in mixed reality experiences that:

- Aid in developing foundational design framework for physical spatial forms and digital asset integration, organization and usage
- Have the potential to engage varying sensory perception, learning and interaction modalities
- Afford discovered conceptual pathways and insights of opportunity for designers, researchers and developers from a panoply of related disciplines to iterate and improve upon the Mixed Reality design process

Ubiquitous computing is migrating beyond the realms of the traditional computer workstation/laptop and into the spatial volumes of our living spaces via augmented/mixed reality applications. The environment and all its attendant virtual/physical features are the operating system with a vast landscape of developmental possibilities looming upon the horizon. This necessitates the need for research and interrogation between the virtual and physical layers through designers working cross disciplinary between Interior as well as Digital Media Design veins of development. Practical applications for the installation of Mixed Reality 3D user interface interior layouts could include retail or all-purpose public access spaces, research laboratories, entertainment, residential or educational venues. Designers of the future could collaboratively design and implement hybrid interfaces for such locales.

My methodology follows the conceptual design as research approach over the course of the six chapters correlating fundamental design ideologies, precedents and interaction modalities from digital media and architectural/interiors design disciplines. This pairing creates a basis for the Mixed Reality Interiors design template along with giving birth to conceptual outcroppings for future feature or device implementation.

The remainder of Chapter one will set the groundwork by addressing design considerations in relation to environmental, art movements or cultural influences upon the development of functional/decorative features in our living spaces along with historical precedents for user interfaces and electronic media embedded within architecture. The notion of interiors as interfaces is discussed along with insights into the basic implementation of swarm intelligence principles in mixed reality setting to aid with organizing environmental media assets in addition to with directing user attention to varying points in space among other uses for this brand of automation.

Chapter two, Proposed Approach expounds upon the design as research methodology for this project along with presenting an initial Mixed Reality Design archetypes framework replete with explanations and examples. The concept of transposing interior design space planning definitions to encompass the realms or virtual media is included within the context of spatial and circulation strategies in addition to spatial relationships.

Mixed Reality Interiors Layout, Chapter three delves into some of the elements necessary to compose a working prototype of these hybrid environments. Input/Output modalities are addressed regarding user perception and interactive possibilities along with step by step concept layout considerations followed by core components that would be useful to have in every mixed reality 3D user interface. The ending sections of this chapter Asset gradients and modulators deal with how the user or automated components of the system can modulate the quantity, quality and placements of digital content in the interior space.

Chapter four, Implementation combines the research, considerations and discovered design patterns from previous sections into a conceptual simulation of a mixed reality environment which includes charts, illustrations and rationale. This space showcases some of the discovered interface and interaction potentials as it pertains to the user's ability socialize, move or exercise, create as well as study in these hybrid interiors. This environment is biomorphic in visually interactive aesthetics embodying abstracted organic process of life drawing analogies between the physical and virtual functions and design features.

Chapter five Evaluation presents a questionnaire along with a host of other considerations and factors to enable designers to gauge the parameters of a solution space during the application of mixed reality design patterns interface concepts. Discovered potentials of the entire design research process of this project are discussed regarding interface improvement suggestions, product design ideas along with environmental psychology implications and veins of development.

Lastly, Chapter six provides an overview of all the topics covered within this research and development project for mixed reality 3D user interfaces included which comprise the summation of results.

1.2 Cultural Climate + Historical Precedents for AR in Interiors and 3D User Interfaces

Creating successful Mixed reality user interface schemes foremost involves an examination and interrogation between the digital and physical layers of these environments from a historical context to understand the background and subsequently draw lines of developmental design inquiry.

Augmentation in the current vernacular suggests interactive digital enhancements or overlays on the built environment. However, before the advent of digital media, art, architecture and the interior volumes of space articulated by the latter comprised the original enhancements. These augmentations served to convey practical information vital to the functions of their site or society along with relaying cultural meaning. [1]

Beyond the realms of qualitative aesthetics or personal preference based on habitus, the majority of classical as well as folk architecture nurtured a strong connection with mathematics in the visual culture through use of decorative and structural elements imbued with subdivisions and scaling amongst other fractal properties. Fractal geometry is an example of technology that can penetrate into the core of a design composition. [22] These fundamental design or architectural fractal attributes mimic mental and pattern recognition processes in the human brain as well as forms in the natural world through existence in an immersive symbiotic web of reciprocal relationships. [24] This design convention is significant because modern science has verified that archetypal keynotes of these fractal elements have the inherent benefit of enhancing cognitive function including feelings of connectedness and other positive emotional states. [23]

Modernism ushered in by the twentieth century international style machine age conventions removed fractals from the visual culture of the built environment and replaced them with empty rectangles and planes with sometimes random and chaotic forms. This was an assault on the human visual processing system because our systems have evolved via organization of biochemical complexity and the elements of the environment manmade or otherwise should be reflective of our natural state of processing information to produce harmony. [22]

Post-Modernist and Deconstructivist architects rebelled against these international style minimalist notions and sought the reintroduction of subdivisions and curves into their compositions. However, with few exceptions, there has yet to be a full reintroduction of fractal properties in the built environment with contemporary designs typically in service to arbitrary stylistic dictates. [22]

Mixed Reality environments affords media and interior designers the opportunity to once again redefine the visual culture of our environments with the novel developmental possibility of reintroducing the regular occurrence of fractal elements of organized complexity into the physical and virtual structures, user interface functions and systems of interactivity.

Salient aspects of traditional fractal African settlement forms along with classical Gothic architecture is examined to provide two examples out of the many historical visual references of how and why designers should remediate some aspects of these artistic schemes with the design of hybrid interiors.

1.2.1 Traditional Augmentation in Indigenous and Classical Art and Architecture

Organization is crucial to the function of all mixed reality design layouts through use of perceptual holisms to understand the interrelatedness between virtual and physical features in a living environment.

Fractal properties and methodologies of design were imbued in the architecture and wares in some of the earliest African societies as a means of weaving a holistic phenomenological fluency of the connections in life between mundane survival practicalities, lineage social hierarchies and belief systems as Eglash a system engineering and ethnomathematics researcher notes. Self-similarity was utilized in the Ba-ila cattle herder Zambian settlements through use of a repeated ring like structure with attached living quarters. Each ring served to house livestock as well as a family and while the shape remained constant, the size at each level of scale throughout the village denoted social status in the tribe. Adaptive scaling or optimization engineering techniques were used during the construction of household windscreens in the Sahel with the density of weave corresponding to the height necessary to block out local windstorms with the rest of the fence being a less condensed pattern. Recursion is demonstrated in the Ghanaian Batammaliba homes with soul mounds being divided to create others mounds as a representation of the living and the dead. The fractal dimension of organized complexity is depicted in the spectrum of order to chaos demonstrated in the raffia palm textiles of the Bakuba. Infinity is shown carved into some household wares as the river god Tanu, a logarithmic spiral motif symbolizing a spiritual force which links all things. [21]

Useful insights for beginning to redefine digital media in an organized environmental setting are to be derived from these examples regardless of cultural context. The self-similarity could possibly be utilized in media user interfaces across different scales of the interior to help acculturate the user into interactivity functions without having to learn a new system at each scale transition. Scaling could be utilized with media assets to denote optimization for a zone in space or degrees of importance such as current events or status messages. Recursion can be utilized to carry out certain automated system user interface functions or organizational templates while, the fractal dimension can be spatially transposed in terms of media complexity gradients relevant to areas of the interior and associative thresholds of intake. Infinity could refer to how all the virtual and physical elements of the space are networked, relate and are able to be transcoded to fit the parameters of varying spatial layouts.

Al Goldberger has been able to identify these fractal properties in the stained-glass windows, spires and overall Gothic cathedral architecture as well. Most pointedly as a scientist while being inside one of these structures he notes how the outward representation of the space's branching design features, among many other attributes closely mirror biological process of anatomic structures. The whole perceptual experience he likens to an account of self-discovery. [27] As Harris notes,

> "Across cultures, people perceive the stained-glass window to possess more life and appreciate it more than the builder's double-hung window. They project qualities that innately connect to humans and make them increasingly "whole" and increase the quality of "life" within them. This causes a recursive cycle between the experience and the observer, augmenting the perception of life from the outside and feeling of life within." [7]

This translates in user interfaces to the designer incorporating interactive and design features that foster this type of feedback through utilization of fractal ideological patterns so that the user can be embedded into the material flux of the space rather than a passive spectator. Augmentation in this sense is built into the core structure of the design framework in both a virtual and physical context.

Fractal's are nature's most effective organizing principle for dealing with the seeming chaos of the natural world. It follows suit to utilize or remediate these principles when developing the archetypes and interfaces of interactivity for mixed reality. The variety of media content within these interiors represents the chaos element that needs an equal measure of structure introduced to enable users to understand and navigate around the system. The dominant emphasis for successful mixed reality design should be within the purview of organized complexity.

1.2.2 Digital Culture in Architecture and User Interface Precedents

Twentieth century precursors to modern AR systems in the most simplistic sense includes electronic billboards/signs as well as sensors and basic projection technology. The designers Robert Venturi and Lars Spuybroek serve as important precedents to consider when researching the background of strengths versus weaknesses to allow for future developments into the best approach for incorporating interactive media and 3D interfaces into interiors.

Robert Venturi was one of the first designers to experiment with some of the contemporary notions of placing electronic digital media signage and billboards in the architecture of physical spaces as a means for real-time iconographic representation of information during the sixties and after. Some of his writings are considered the cornerstone of post-modernist thought that are in direct opposition to Adolf Loos notion of ornament as a crime in modern dwellings. While the electrical component of his designs was novel, his work did not take into consideration the totality of the spatial volumes in which they were situated and can be compared to the works of the artists who relegated themselves to the 2D space of the gallery wall or meant to be viewed as singular isolated entities. [1]

Lars Spuybroek's Freshwater Pavilion created in the mid-nineties serves as an excellent example of our burgeoning technological era as it utilizes computer-controlled lights, sound and eliminates all straight surfaces. As Manovich notes,

> "The space is not the symmetrical and ornamental space of traditional architecture, the rectangular volumes of modernism, nor the broken and blown-up volumes of deconstruction. Rather it is space whose shapes are inherently mutable and whose soft contours act as a metaphor for the key quality of computer-driven representations and systems: variability." [1]

While I concur with the author as this being representative of the information age in an abstract sense, it does not present a system or pattern language template from which designers can concept future networked interior living spaces replete with embedded Augmented Reality media. From my observations, if the design methodologies of Lars Spuybroek and Robert Venturi were combined along with utilizing fractal pattern elements, it would yield effective results towards this end. Spuybroek designed the spatial volumes in accordance to the mutable essence of the electronic information but the useful content was lacking besides abstraction. On the other hand, Venturi's works displayed useful content but did not interrogate the dimensionality of the space and were situated inside a traditional linear context. It would behoove future designers to take these precedents into consideration moving forward in their practice to create mixed reality, digital/physical environmental spaces with organized complexity. [1]

From a historical context, the idea of user interfaces was spurred as a result of mid-Century a pioneering computer scientist Ivan Sutherland who injected the notion of computers being utilized for a wide range of interactivity possibilities into the public consciousness. He developed one of the first head mounted displays with tracking technology which gave rise to the developmental field of interactive interface research. Prior to this time and decades after, computers were seen for their mathematical utilitarian functions and remained so until the eighties saw advancement in technology enough to explore these other options beyond command line processing.

Input and output technologies such as the computer mouse as well as displays which supported raster graphics enabled the development of the first graphical user interface known as the Xerox star. Modern computers and smart devices are representative of current day developments in user interfaces with icons, desktops, search windows widgets and 2D graphics. [25]

However, with the advent of advances in Augmented Reality we are at a time now where 2D user interfaces exclusively will not suffice in this virtual/physical 3D context. Though, some of these elements and concepts can be remediated. The environmental space, how one moves and interacts in these areas in addition to spatial relationships/interior design principles must be taken into consideration among a vast array of other human computer interaction design guidelines. [22]

The concept of techno morphism deals with the designers/artist of a certain era or particularly the technological one giving rise to the construction of art forms, spatial arrangements and concepts based on and in support of the inherent logic of current computing practices. [18] In the present-day context, this translates into designers examining our current cultural climate of networked digital media platforms and patterns of usage and adjusting their design practices to dovetail and further innovate upon current trends or forecast into the future. Our computers and devices are networked mutable and consistently updating, but can the same be said for the spatial volumes we inhabit? Augmentation in the present tense is seen through the 3D interactive media arts and innovative digital physical technologies and the design of mixed reality environments must reflect this polyaesthetic, multidisciplinary approach to maintain cultural relevancy. Further research and investigation is necessary in this vein in efforts to develop practically effective 3D user interfaces. [16]

1.3 AR Theoretical + Media Design Considerations

Advances in input/output modalities and software enables designers to shift the orientation of this medium into what Jakob Nielson, a media researcher has termed a lean forward medium. Lean forward mediums are characterized by the user's ability to interact with the system and receive feedback as opposed to lean back mediums where the user has limited or no interactive capabilities beyond the initial activation and is situated in the role of a passive observer. [12]

Mixed Reality interiors fundamentally gives rise to the cultural reinterpretation of space through enabling local attributes of an environment to be simultaneously global and local. This section aims to explore some of the meaning making potentials and implications whilst operating inside these hybrid environments. How and why will the media that we currently consume adapt and transform into the visual composition of our living spaces beyond the context of the 2D screen in a functional, environmentally integrated organized format? [4]

In the Poetics of Augmented Space, Manovich presents a similar concern of media forms drowning out rather than complimenting the pre-existing spatial layouts in stating that one must go "beyond the surface as the electronic screen paradigm" in thinking about the material as well as the immaterial architecture of mixed reality. [1]

The primary reason why media needs to adapt when transitioning into augmented reality is because the user is now more immersed in a multiplicity of visual realities and universes ranging from social, educational, occupational or even in entertainment worlds. Coupled with this notion, the user is also placed more prominently in the director's role of in choreographing the mixed reality elements inside their spaces.

Early developments of augmented reality applications could be likened almost to a novelty in public consciousness where an individual could point their phone and certain fiducial markers, objects and landmarks to receive additional information or multimedia given the context. [12]

An example of this type of application situated inside a cultural institution was Manifest AR which occurred in 2010. This was an augmented reality takeover of a portion of the museum of modern art in New York in which virtual art objects were superimposed upon pre-existing contents of the interior space viewable through the patron's smart phone or tablet devices. The augmented reality melded the roles of the curators, venues, artists as well as the audience into autonomous yet equally connected entities through the introduction of these digital assets with the ability to alter the venue, control the viewing angles of the objects of perception and turn the application off at will. [4], [2]

One weakness of this endeavor is that there were limited user interactive opportunities for modulation of the media observed beyond gazing at the virtual assets from varying orientations. This highlights an important developmental possibility for mixed reality interiors as more complex media and data streams become prevalent in our environment, there is a necessity for a system of modulation and organization. In the second section, 1.2 utilization of fractal principles for organizing the hybrid interface was mentioned as a starting point and this concept will be examined in later chapters.

However, ideologies about modulating this complexity need to be addressed foremost which will be approached through relevant case studies and investigations into abstract expressionism, impressionist as well as baroque art forms as they relate to and inform the mixed reality design process.

1.3.1 Mixed Reality Choreographing Pt.1 - Remediating Impressionism, Abstract Expressionism and the Baroque

Impressionism, a late 19th and early 20th centuries art movement placed prime importance on depicting the fleeting moods and atmospheric effects in a multiplicity of settings through use of a layered buildup of color and texture to provoke visceral response in replicating the immediacy of visual impressions rather than contrived realistic accuracy of traditional paintings. According to Aaron Scharf, an art historian, the artist's working in this movement derived inspiration for their painting from the cultural inception of photography with brushstrokes of abstraction mirroring the exposure effects in early photographs. [8]

Tinnell, a media researcher asserts that impressionist accomplished their works through a transfer or transcoding of the "visual logic of the photograph into the perceptual experience and principles of composition. Artists and developers working with mixed reality can employ the same transcoding process through use of layered media effects normally attributed to a conventional computer interfaces like photoshop among other examples to introduce "new dimensions of materiality, indexicality, and spontaneity into the production and circulation" procedures of these novel mediascapes. [3]

I propose the use of gradients and sampling of media assets and elements in 3D user interfaces to work towards these ends. For example, in accordance to the spatial composition of an interior, the sampling in both quality and quantity of media assets could differ from one area to another. A mixed reality space devoted towards study and learning would have a different gradient of media process and effects as opposed to a dedicated space for socializing and entertainment. Gradients could also be dictated by the spatial scale attributes of the area.

Mixed reality users will inhabit real-time dynamic interior layouts composed of medley of media entities whose distribution and expression are predicated upon user or system modulated gradients. The groundwork for concepting these interfaces lie in establishing a spectrum of gradients relevant towards the space design and interaction goals akin to how the impressionist created values of paint on their palette. Augmented reality expression or programs are not singular isolated entities, rather part of the mediascape of future interiors and consideration of gradients is the initial step in the design process.

Abstract expressionism an artistic movement which occurred around the mid-20th century was characterized at its onset by uninhibited and spontaneous forms of emotional expression in a wide variety of techniques and styles. Intuitive, musical and fluid applications of paint or manipulation with similar media was the hallmark of the action painting period of the movement and most applicable to be utilized as a starting concept for the modulation of media in mixed reality settings. [29]

The actions pursed in life derive largely from intuitive, emotional, and logical factors among others that occur because of various environmental stimuli or innate responses. From a user interface standpoint, this is an important vein of development to consider when designing effective mixed reality interfaces that are appealing to the sensorium of varying users. Recent scientific studies have been conducted on the seemingly chaotic painterly elements of a well-known abstract expressionist, Jackson Pollack to discover that his works of so called abstraction are poured paint fractals. Further investigations revealed that the level of complexity or fractal dimension D of certain natural or man-made elements in environment impact the human neurological, perceptual and physiological processing systems with regularity regardless of cultural context. Studies undertaken involving public exposure to Pollack paintings with different levels of fractal dimension uncovered that humans prefer design features with a mid-range level of complexity from 1.3.-1.4 on a scale from 1-2. Besides simply preferring these levels of aesthetic complexity, the field of environmental psychology has described this mid-range fractal dimension features as having instorative effects or improvements in feelings of well-being and overall psychological health resulting from such configurations. [26]

Incorporating design features in a mixed reality interface setting with a mid-range fractal dimension to generate a restorative environment would be another useful consideration to aid in the modulation of media assets that would enhance the user experience.

Baroque art and architecture parallels the developments of augmented reality in its aims to combine varying sensory evoking design elements. This movement escapes the confines of traditional frame and stylistic representations of 17th century Italy by blurring distinctions between compositions just as augmented media seeks to escape the frame of the 2D context. Paintings, sculpture and architectural elements depicting movement, size and color variances sought to convey emotion and augmented sensory experiences. This occurred through the juxtaposition of the spiritual with the sensuous whilst destroying boundaries and borders by having design features permeate in all directions as literal and figurative expressions of infinity. These infinite compositions rely upon the perceptions of the spectator to find the center and order space for themselves much like AR/MR media requires the user to be in the director's seat in varying capacities. Mixed reality however moves beyond just static imagery depicting infinity into embodying the infinite through digital network connections in combining a wide array of graphical schemes, program types and functions of interactivity to provide the user with multisensory experiences and real-time interactions with vast meaning making opportunities. It is also infinite in the sense that there can exist an unlimited amount of virtual assets and interface elements anywhere in the interior though it is crucial to consider inter-object relations, design patterns and the overall composition of a mixed reality interface layout just as past artisans would construct baroque artforms with consideration of context in accordance to the tenants of the movement. [28]

In remediating baroque ideologies into the technological era, it's important to update the cannon of practices in accordance with enhanced affordances so that the original set of rules does not become a limiting developmental factor. The important point to consider in designing 3D interfaces catered towards mixed reality is to design for the user to have a participatory role in being part of the action in directing the composition of sensory feedback systems though their own interactions.

O. Samanci created an installation entitled "On the Air" which was an interactive project showcasing site-specific embodied user interaction potentials with non-homogenous design elements. It offered users participatory exchange through utilization of sensors, projected animations and physical props. A table was set up with a vintage radio alongside a wall where a contrasting 2D animation sequence of musicians walking into the radio was played. As a user comes into proximity, the musicians quickly run into the radio and music begins to sound. [5]

In this example, the orientation of a user serves to alter the design and feedback expressions of the setting. It effectively communicates interaction parameters through utilization of musical association commonalities to blend seemingly disparate design elements of the old-fashion radio and animated musician stick figures.

The same concepts in this example are applicable to mixed reality interface design such as placing the user in the director's seat at the center of the action, blending different media elements to convey a message and to provoke emotional response or desired feedback from the system. Another point to consider is that virtual elements in a hybrid environment don't have to match in terms of stylistic realism to the physical environments they inhabit for them to accomplish immersive design and interaction goals.

From Impressionism we learned that a spectrum of gradients needs to be established for augmented media asset expression while our Abstract Expressionism case study revealed that while context may vary, human beings are hard-wired to respond similarly across the board to certain levels of fractal dimension visual complexity with the preference being mid-to low range. What we perceive as abstract and a product of our own world-view or emotions could in fact exist within the range of organized complexity. Lastly, Baroque has emphasized the infinitely unbounded, heterogeneous and participatory nature of structure, art and media forms. Individuals are there to participate and be the director of their mixed reality experiences while also perceiving that they are connected via networks to something larger than themselves. These notions communicated and felt by the user are also reflected in system processes.

Taking these movements and associative design patterns into consideration, which can be remediated into mixed reality experiences would be a useful first step in helping designers to conceptualize and order the compositions of these novel environments.

1.3.2 Mixed Reality Choreographing Pt.2 - Graphical Representations of Swarms

In addition to choreographing mixed reality elements the basis of past cultural design movements, observing the organizational structures and hierarchical patterns of living entities in nature could provide some insight into the incorporation of automated standard functions in augmented reality. In this capacity, the biological foundation of swarm intelligence will be examined with respect to how the designer can graphically represent, order and program the animated behaviors and modes of interaction in this digital/physical space. Members of the swarms in an organic sense include groups or clusters of animals or insects that follow collective behavioral patterns for purposes of migration, foraging and communicating crucial information relevant to daily living and sustenance. For our purposes here, individual units of the swarm are likened to virtual media assets which could follow the same collective behavioral patterns in the mixed reality 3d user interface.

According to Beekman et el, swarm intelligence has two primary recruitment systems to facilitate collective behavior. These include, direct as well as indirect recruitment mechanisms. An example or indirect would be the pheromone signatures certain ants leave behind to either attract or repel colony members to food sources either abundant or exhausted in addition to structures or conditions suitable for housing and nesting. The dance of a bee to indicate food housing and resources is an example of a more direct approach to order the behavior of colony members. Yet, with both approaches there exists an inherent possibility of randomization because inevitably, some of the insects will get lost on the path or not interpret the signals correctly, and those members become the intrepid scouts for the collective. They seek out new resources beyond their known universe. [14]

Before I continue with the last explanation about swarms, it's worth noting here some of the practical applications that can be developed in AR derived from this knowledge. The first and most obvious is that Augmented animated media asset particles or light trails utilized to direct inhabitants or users in an AR setting to help choreograph the sequence of events in a cohesive format which is almost akin to the pheromone signatures discussed. Film has developed a set of conventions to automatically lead the spectator's attention to varying places on the screen, but mixed-reality has yet to develop a set of such rules of composition. When a story or interactive experience is being dictated in AR, this method of utilizing animated trails of media asset particle arrays, graphics, gestures or even sounds could be an initial approach.

Secondly, instead of the usual text based instructional system, perhaps more can be done with movements and gestures to manipulate and interact with media assets in this Augmented Reality Architecture as the interface environment. A plethora of possibilities exist, and these are just a few.

Lastly, it should be noted how swarms are organized and led without the traditional hierarchical structure of a leader. A concept known as quorum threshold or critical mass is introduced as a method for order in such circumstances. This can be defined as the command of the group or swarm following in suit after a set number of individuals of that group form an introductory pattern or strong enough call to action. Once this is achieved, phase transition will take place with the group being led by the template of these pioneering members. This relates back to digital media's organization of assets because a user now has a means to efficiently organize their personalized cloud media assets in their AR living space through automation. They could be assisted in their organization efforts by a swarm structures such as this forming pattern templates for purposes of order and accessibility and these schemes could also be organized with fractal attributes in mind serving as decorative/functional features in the hybrid environment. [14]

1.4 Interiors as Interfaces

The virtual and physical architecture of interiors is now becoming the computer interface and Mixed Reality paradigm necessitates a formalized design framework to construct interface features for users to navigate the range of interactions within an environmental media landscape. Current forms of augmented reality systems are fragmented in the sense that they are isolated entities not part of and reactive to a larger ecosystem interface of other programs when they are executed in an interior. These augmented reality programs are in registration with environmental settings and reactive in site specific contexts but not much design consideration has been given with regards to balancing and choreographing the digital and physical content, context and inter-object relations within a composition of the whole interior.

The notion of interiors as interfaces presents an inquiry of how Mixed Reality spaces can be implemented in a virtual and physical context. Utilizing interior spatial layouts and architecture as an intervention would be a useful first step in its abilities to ground and interconnect and act as a conditioner of media experiences while also being conditioned itself. [16] This section will present a three-step process tree to start to answer the questions surrounding mixed reality environmental integrational with each successive process being informed by the latter. This will present designers with analysis of related background research and case studies to consider when prototyping and integrating these mixed reality 3D user interfaces.

1.4.1 Process Tree

Cognition and Culture

↓

Media Gradient Spectrum + Built Environment

↓

Scale Modulators

1. <u>Cognition and Culture</u>

The way that the human mind processes information from environmental stimuli influences the individual's actions in the creation, design and arrangement of the same elements of the built environment in accordance to culture. Cognition is also molded via naturally occurring processes of the human body as much as it is by the conventions of culture. Culture and cognition are reciprocal as they perpetually reproduce one another. [22]

Given consideration of this notion, it is the task of designers to reflect these cultural conventions in the structures, processes and interactions of the built environment along with introducing complementary elements based upon societal or developmental trajectories, the design goals of specific clientele and psychological factors reflective of instorative elements of the natural world.

Participatory culture, a dominant cultural developmental trajectory aligns with the ideals of techno morphism stated in section 1.2 which entails developers and designers modeling systems of design in our environments after the inherent logic of our computing practices. Smartphone devices, and interactive applications have become an everyday computing practice in our society and this interactivity should be reflective in our interior surroundings as well. [18] This is where mixed reality design processes come to the forefront as it's not merely replicating what the interface on these devices can do but it is also affording the user with an additional layer of immersion to participate by operating inside of the system rather than outside. This serves to enhance certain programmatic functions while also reaping some of the benefits of operating in the physical to maximize the relevant affordances of both worlds.

Another important cultural factor to weigh into consideration when designing these interfaces for everyday use is the research projection that by the year 2030, most of the population in urban metropolis settings will have increasingly seldom opportunities to encounter living elements such as green acres and the accompanying flowers, plants along with other types of natural geographic features. [24] As relayed in previous sections, natural features of our living environments many of which exhibit fractal properties are the root of instorative psychological benefits of clear and enhanced thought processes as well as emotional well-being along with accelerated recovery times for hospital patients. [23] Besides, pure functionality, the visual culture of mixed reality environments must be considered in terms of modeling the physical/virtual features and interactions of these spaces in the likeness of biomorphic or fractal properties. Benefits of this organic form language can be reaped even in the manmade or graphical artistic sense. [24] It would behoove designers and developers to incorporate these elements as a baseline standard for Mixed Reality interface compositions as it is ethically sound while also mirroring the reciprocal influence nature has on the built environment as researchers and designers alike have always investigated the natural world to solve problems in every facet of life. As Harris notes,

> "A similar phenomenon occurs when humans are exposed to objects structured according to fractal geometry. The neural circuitry of the scaled self-similar structure in each object causes similar neural pathways to be used, which cause analogous physical, cognitive and emotional effects." [7]

2. Media Gradient Spectrum + Built Environment

Once the design trajectory has been set by cognition and cultural factors or the specific design brief of the setting these elements determine and drive the overall media gradient spectrum along with the design composition of the built environment.

The media gradient spectrum refers to the range, variety and complexity of experiences to be had in mixed reality through interaction with immersive multimedia. In general circumstances, the mixed reality gradient spectrum has infinite potential and is only limited to and by the availability of augmented reality and interactive functions present and yet to be created. While the spectrum is unlimited, the expression of these environmental media artifacts is throttled by compositional factors of the physical interior's spatial strategies and relationships varying from area to area. For example, the media gradient in a walkway would differ from that of a research lab in content along with functionality. This is an instance of different spatial zones in an interior conditioning the gradient effects of certain regions though another factor to consider is that these gradients are not fixed values. Part of incorporating digital culture into architecture is through its reactivity to the presence of people and users either virtual or physical and this interactive quality embodies the participatory aims of contemporary media culture.[16] An instance of this is that even though the walkway may have a designated media gradient, the individual walking along this route could potentially alter the settings and composition of media elements in this space by overriding the defaults for personal preference. Additionally, mixed augmented reality media elements could appear on the interface in the area only when it is populated by people or a select range of individuals, many variables exist. In web design terminology, there exists the notion of responsive web portals and interfaces, and these concepts are being remediated here in mixed reality to encompass responsiveness the spatial features in the environment along with the presence of users.

Another important factor to consider is how the structure of the interior space will change because of digital media integration. Architecture in mixed reality interiors through embedded sensory arrays among other novel implements will be able to script and modulate the thick of the virtual atmosphere and some researchers theorize that augmented reality will "weaken the role of partitions since walls may lose part of their relevance in a geography" governed equally by physical as well as electronic boundaries. [15], [16] The interior architecture should also be considered in terms of altering the physical and functional aesthetics to accommodate the mixed reality media presence. In this aim, designers can refer to the Lars Spuybroek water pavilion precedent mentioned in section 1.2. This interior made use of biomorphic design elements with sensors as the surfaces were organic and continuous to mirror the cultural mores of the infinite information stream of the networked digital age.

The important notion to catalogue here is the intentionality of the design of the physical space with the digital in mind instead of it being an afterthought. Intentionality when executed properly will bring about balance between the physical and digital elements of these hybrid spaces rather than the converse which would yield one-sided, top or bottom heavy interactive experiences. The goal is to modulate the user's sense of immersion in mixed reality 3D user interfaces across a range of gradients some to a lesser or greater degree appropriate to spatial orientation and design interaction goals.

The Solovoid exhibition review case study typifies the relationship explicated here between electronic media gradients and the built environment. Solovoid was a large-scale exhibition of an indoor installation of a suspended abstracted biomorphic stem cell formation which was termed a media organism because it was embedded with digital sensors and projectors reactive to the movements and presence of visitors passing through. This installation sought to blur the perception of physical and virtual realities through use of electronic media involved in the modulation of the surface and spatial volumes carved out by the suspended structure. [10] The important point derived from this example is that by being present in the physical space does not have to denote absence in the virtual world and vice versa. By establishing and modulating media gradients based on environmental layout, cultural values, design aims along with cognitive affordances, a designer can achieve this balanced blending of digital/physical features in the interfaces of Mixed reality environments.

3. Scale Modulators

Scale is the modulating factor of gradient expression in certain areas and interactions in space. It is driven by and drives the composition of the gradient spectrum mapped within and onto spatial interior layouts. Scaling is one of the fractal attributes which is integral to the function and driver to all other fractal properties which include self-similarity, the levels of complexity perceived in the fractal dimension, our notions of infinity as well as how we can relate to and define recursive elements in space. Chapter 2 will detail the role the other fractal attributes contribute within a mixed reality composition, but scale will be focused upon here for its dominant relevance in modulating the nature of mixed reality experiences.

When thinking in terms of how scale is applicable in these hybrid environments, the initial impetus is draw knowledge from fields of study such as geography to remediate spatial scale definitions to fit within our immediate context. Egenhofer and Freundschuh distilled schemes for classifying these scales into six distinct categories which media researcher Barba found relevant to couch in terms of a mixed augmented reality spatial scale framework. This is useful because it helps designers to organize, prioritize along with begin development of the design and interaction goals best suited for each of the scale classifications. These spatial scale classifications include:

1. Figural - akin to human proportions,
2. Panoramic – larger than the human body, yet capable of being perceived from a solitary location by means of rotation, or panning
3. Vista – a subsection within panoramic scale that allows individual to perceive one vantage point without any movements of rotations
4. Environmental – larger than the human body and viewable only by means of translation through space, walking or a traveling motion
5. Global – spaces that cannot be directly experienced and therefore require a map or model as a means for representation
6. Map space – projection of higher scale spaces onto lower scale spaces which provides symbolic representations of compressed information

Another scale to be factored in addition to this frame work in MAR is semantic scale which refers to the way that media assets can be assembled together to generate new lexicons of meaning for users. [30]

Studies conducted in the cognitive science field by Hegarty et al have determined that human spatial abilities are not uniform across varying scales of space. Initially, researchers, split spatial scales into two categories, large and small and then subsequently made hypothesis about human capabilities. Out of the four theories, tested, only Partial Dissociation Model has been verified for accuracy which states that some cognitive abilities are similar at small and large scales while others vary. Designers and developers are now tasked with creating interfaces optimized for mixed reality interactivity based on the six spatial scale classifications listed rather than the simple distinction of large and small with the knowledge that some human capabilities remain constant while others vary between the levels.

An important discovery to note here especially considering modern augmented reality applications such as Pokémon Go is that it's perfectly acceptable to create a heterogeneous mixture of spatial scales within a single application. This app features an environmental space nested into a panoramic one which yields an expansive perspective of the surroundings that would be impossible to view in real life. While this app mixed spatial scale elements in a graphical format, the varying types of interactions suitable at different scale classifications are also an open candidate for mixture and experimentation. Within the paradigm of user interface design, this is what is defined as multimodal input processing. The user is connected to a system and utilizing a range of interaction methods suitable for each task instead of one umbrella technique to interface with the application. This streamlines the user experience by scaling each method of interaction to the affordances of the activity. [25]

A case study utilizing arbitrary surface displays or projection mapping on artifacts and interior architectural features inside of various cultural institutions is another example showing how designers can begin to implement scales of media simulations into the surroundings.

These installations which were set up at museums and tradeshows demonstrated 3D projections onto physical objects and many useful design principles were culled from these research experiments. The three insights gained concerned new potentials for well-known 3D effects, dynamics between the digital and physical world in addition to the relations between object, content and context. One of the most important revelations is that content should be developed always with the physical in mind in regards, to scaling, complexity and subjective context. This mirrors our discussion thus far outside of this example and helps to further solidify the veracity of this notion. In the study, a statue in a Denmark museum Holger the Dane was selected to have digital content projected onto its surface. The media designers sought to convey this historical/mythological figure through additional augmentation on the surface of the statue yet found that the design features of the sculpture contained a high amount of detail. Consequently, designers adapted their approach from utilizing complex text or visualizations that would occlude the physical surface detail to dovetailing animations and particle effects procedurally generated across the surface of the object. [6] Instead, information about the statue was relayed through sound and animation on portions of the statue to draw attention to aspects of the story or explanation. This museum exhibit was an example of how the complexity scales of the augmented reality media simulations were modulated to account for the spatial forms it was being projected onto. The digital and physical complement each other to achieve an informative and entertaining exhibit experience. Animations were utilized in this museum installation to lead the visitor's eyes and attention into varying levels of scale on a single statue and I think designers could utilize this media technique to deal with transitions between the spatial scale levels along with other factors that will that will be considered below.

Barba also brought up the concern in these environments over fluid transitions between these spatial scales in each setting. He likened scale transitions in mixed augmented reality(MAR) to cut sequences in the filmmaking paradigm and created an installation entitled Inbox which sought to address some of these veins of mixed reality pattern language development. It entailed working with spatial scale transitions between a few of the six classifications to experiment and discover methods of creating substantive connections during augmented cut sequences.

The installation sought to convey in Mixed Augmented Reality reflections upon the histories and implications of shipping containers and how these mobile storage units contributed to the establishment of the globalist era. The user was outfitted with headphones and a smartphone or tablet viewing device as they entered a large walk-in shipping container consisting of 3 stations of physical and virtual props accessible through augmented reality fiducial markers placed strategically. It was discovered that user's appreciation of the subject was overall enhanced through mixed reality media projections, however, making transitions between stations situated at different levels of scale proved to be disjointed in the sense that they left the exhibition space without a gestalt or holistic understanding of how each of the stations were connected to convey the larger meaning. The participants were not able to fully relate to content at each side of the transitions in a substantive manner. [13]

In my own analysis of this issue, I think that all properties that make up fractals not just Scaling need to be considered when constructing these augmented media experiences. Scaling plays a large role in helping us to understand spatial classifications and corresponding developmental cues yet leaving out the dovetailing components that imbue scaling with substance order and purpose works contrary to the tenets of holistic design philosophy. As Harris notes, "The structure of the nervous system is configured to identify forms that exhibit fractal characteristics as significant organized wholes". This sets the stage for designers to think about how fractal attributes on an either graphical or interactive methodological sense or even both can be integrated into mixed reality 3D user interfaces, so the user can easily navigate, understand and participate in the construction of semantic meaning in these hybrid spaces.

2. PROPOSED APPROACH

2.1 Design as Research Methodology Overview

Consideration must foremost be given to the foundational organizing elements when approaching the design of Mixed Reality physical/virtual spaces. It is the aim of this section to correlate established archetypes of development of interior design patterns and spatial strategies with digital media principles couching the most relevant aspects in terms of holistic fractal design principles. Salient concepts from the literature review as it pertains to augmented reality and interior design will also be utilized to informatively flesh out this methodology and the development of the simulated prototype in later chapters.

In the previous section we cited historical as well as modern research indicating that fractal design patterns in one's environment gave rise to positive cognitive response resulting from intellectual growth and stimulation through pattern recognition and attendant meanings within the context of a given habitus. I theorize that utilizing fractal elements to help the user interface, navigate along with perceive patterns within these novel environments is a sound basis as well as barometer for future designers to prototype augmented reality UI interior layouts. In this vein the designer would be able to initially gauge the effectiveness of their endeavors as a precursor to testing and other research methods to fine tune at another layer of granularity beyond the scope of this thesis.

The design goals or thematic focus of any given mixed reality environment be it residential, public or commercial will always be subject to high variability though it would behoove each layout to fundamentally embody the methodology of wholes and nested centers at its inception to ensure a basis for environmental readability regardless of the user's virtual or physical spatial orientation.

This design concept of wholes and nested centers as elucidated by C. Alexander states that centers are coherent microcosmic focal points that support the configuration of the macrocosmic whole. To translate, on a base level the parti, thematic or functional purpose of a living space which can be considered a whole should possess spatial arrangements and media assets (which we will consider the centers here) that support this living idea. [11], [20]

The creation of strong centers and wholes is sought after in nearly all compositional arrangements across the design fields and this aim should not be different when working with the mixed reality(interiors/physical) medium. Perceiving these modalities in terms of their relational co-creative aspects will achieve this end.

This concept is well known within the Interior/Architecture disciplines yet within Digital Media, this means that designers must extend their design context outside of the 2D computer screen and take into consideration the physical space beyond 3D digital assets simply being in correct physical registration with the environment. The questions of what types of media assets and information should be incorporated into these spaces in addition to where and why needs to be asked. In turn, Interior Designers must consider the presence of Digital Media in their environments as a viable compositional element as one would view furniture, lighting, decoration, structural elements etc. and modify their designs accordingly to accommodate. [19], [20]

2.2 Mixed Reality Interiors: Design Archetypes

In the first book of the Phenomenon of Life by C. Alexander, a list of fifteen design patterns were discovered as a basis for architectural or interior arrangements to embody strong nested centers which support the wholeness, unity or overall thematic focus of an environment. Effective centers must demonstrate their relatability to one another in their influential interactions between themselves and the larger whole of the environment. Although, patterns for sound centers are not limited to this list and many more await discovery, I have selected five of these elements which I found to correlate best with digital media principles and the overarching fractal organizing attributes. [20]

The digital media principles as outlined by L. Manovich constitute the building blocks for digital software creations regardless of complexity and are a necessary inclusion when merging both physical and virtual paradigms of design for future mixed reality environments.

The chart below displays these correlations made to provide designers with an introductory template of the proposed relations.

Table. 2.1

FRACTAL ATTRIBUTES	ARCHITECTURAL/INTERIOR DESIGN PATTERNS	DIGITAL MEDIA PRINCIPLE
FRACTAL DIMENSION	Roughness + Gradients	Numerical Representation
SELF-SIMILARITY	Local Symmetries + Deep Interlock & Ambiguity	Modularity – *(**This isn't an exact match for the fractal property, because structural changes here at one level does not affect the whole compositional arrangement of the larger form it is nested within. However, this quality will be modified in this case to embody the self-similar attributes while being modular.)*
SCALING	Contrast + Levels of Scale	Variability
RECURSION	Alternating Repetition	Automation
INFINITY	Not – Separateness	Transcoding

Fractal Dimension/ Roughness + Gradients/ Numerical Representation

Perception of an object or space's fractal dimension is all determined by the scale in which it is viewed and subsequently measured. As such an object that is viewed at progressively smaller scales would have and ever an increasing fractal dimension as one is able to see more of the intricacies of the pattern or structure with the converse also being valid. The fractal dimension is one of the cornerstones of strong design system in this vein as it allows the user to perceive an infinite continuum of the creation being focused upon. [21]

The architectural design patterns of roughness and gradients mirrors this notion of the fractal dimension in quality and function. Roughness of a design feature represents the subtle variations in its shape and positioning with respect to where it is spatially oriented. The element of gradients dovetails this quality of roughness as it represents the sectors or measurable transitions of aesthetic modification that is generated by roughness within a larger design system. [20]

Numerical Representation determines how all digital media assets are represented, created and translated into virtual space via binary code of 0s and 1s and in in turn subject to varying qualities as well as resolutions of sampling from high to low fidelity. This translation lends itself to multimedia assets or images and text that are both programmable and programed.

Imbuing a digital/physical interior setting with the ability for resolution sampling is an important design pattern to be included in mixed reality environments as far as the fractal dimension is concerned. [19]

More specifically, context specific or adaptive sampling based upon spatial orientation in a material and phenomenological sense be it within an infinite or finite range of scales is useful. The notion of selective sampling mirrors some of the ideas discovered during the literature review in the necessity of establishing a spectrum of media gradients along with the journal article concerning 3D projections of animation onto artefacts in the Danish cultural heritage museum. Designers of the exhibit as mentioned previously modulated the content as well as complexity of the digital media animations based upon the aesthetics of the object along with where it was placed in space. The same notion is relevant here.

In designing effective environmental 3D UIs, users or designers can set or dynamically adjust the quality and quantity of media in their surroundings based upon cognitive load requirements along with other factors which would lead to a more streamlined user experience. Within a given system, it's best in most cases to create processes in that realm to support the dominant function just we stated in our introduction that centers in an interior should support the thematic goals of the space. By including as well as having control over the resolution of the fractional dimension designers are supported in this aim. Another factor to weigh in about modulating the complexity is the research presented in Chapter 1 that suggests humans have a natural proclivity for mid-range fractal dimension values. While the complexity is being modulating across the media landscape designers might want to consider incorporating this quality amongst other relevant factors at each zone or scale transition.

For example, if an augmented reality 3D UI were to be designed for a study room in a public library as opposed to the loud atmosphere of a night club lounge certain affordances and constraints in the fractional dimension of design features could be setup given the user's ability to process different types of information media in each setting. In the library, the sampling resolution of the interface and functions can be more complex as the person has more time and willingness to think as opposed to a bar situation where the graphical user interface should be simple, bold and stylized to support the function of the atmosphere, to flow in concert compositionally rather than clash.

The fractal dimension attribute affords this freedom of design exploration. [19], [20]

Self-Similarity/Local Symmetries + Deep Interlock & Ambiguity/ Modularity

Fractal self-similarity refers to the quality of the perceivable shape at one level of an object being similar to the original shape at varying levels of magnification. Self-similarity ties in to the previous fractal dimension attribute in many respects as it provides more context to the quality of forms that appear while transitioning from greater to smaller dimensions. If self-similarity is present than a form at one level will have both maco and micro self-similar duplicates as well as some passive transforms thrown in to the mix. With self-similarity, changes at any level of the design pattern or shaping has a cascading effect upon the rest of the composition, it will alter itself to suit the transition. [21]

Local symmetries in addition to deep interlock and ambiguity architectural patterns can be defined as centers in a larger whole of a design system that are made up of regularly shaped smaller pieces that are hooked into their surroundings such that they can sometimes be perceived as unified with neighboring centers and design elements around. A practical example of these principles is displayed in some forms tile-work that utilize design elements at one scale or orientation that are used as a starting basis for the next decorative feature in the pattern. Along with the implementation of local symmetries, utilizing deep interlock and ambiguity fosters a sense of connectedness in the composition due to employing elements of self-similarity from the largest to smallest scales of a composition. [20]

Within the digital media paradigm, modularity is the quality that allows for varying types of media assets be it music, pictures, text, etc. to be combined and transformed into something new or integrated into a larger entity. Everything is essentially interchangeable, can be swapped and layered. [19] An example of modularity would be a musical play list on a user's personal media device with all the nested components that comprise the custom track lists. The user can swap in and out track selections which in turn alter the configuration and duration of the playlist. In some cases, they also can alter the sonic qualities of playback including the volume and any other effects and this gets applied to all the tracks on the list. This is an example of fractal Self-Similarity, because structural changes here at one affect the whole compositional arrangement of the larger form it is nested within. Designers are encouraged to utilize this quality to embody some elements of self-similarity in their 3D UIs when it's appropriately applicable to read to reap the user experience benefits.

The design pattern of self-similarity as it relates to digital media elements of modularity in addition to local symmetries and deep interlock architectural schemes discussed earlier gives the designer another useful roadmap for development.

It provides users with graphical indicators and tools for comprehending function and navigational frameworks between the multitude of user interface scale transitions in 3D UIs. For example, rather than having to relearn a user interface system, selection and placement techniques each time the user navigates to a new area, maximizes or minimizes information or media items, if self-similar organizational patterns are utilized in graphical aesthetics and function, the user interface readability is improved. [19], [20]

Scaling /Contrast & Levels of Scale /Variability

The fractal quality of a scaling shape is a driver for all other properties as mentioned in Chapter 1 as it controls the expression and user's perception of the fractal dimension, self-similarity, infinity as well as recursive elements within the ecosystem of any holistic design composition.

Scaling is tied to the fractal dimension through a fundamental principle known as the scale-complexity trade-off. This terminology which is found in complex systems literature states that when the scale of an object, surface or representation is increased, some of its complexity needs to be diminished while if one were to increase the complexity, the scale should be reduced.

Scaling enables the varying representations of self-similarity in that a scaling shape refers to a natural object, thing or design feature having similar patterns at varying ranges of scale. However, the difference in this case is that it can sometimes operate within the context of a finite range of scales. The core principle is similar of having a tiny portion resembling the structure of the larger object. It's also important to keep in mind that the conditions of scaling vary in application from practical function to optimization engineering as in adaptive scaling to fit the contours of different surfaces to instances of minimizing portions of a design to constrain or afford certain elements an environment, acting as a modulator in this case.

To name a few examples of this within the context of a real-world environment, we will refer to R. Elglash's mention of fractals being utilized in some African tribal villages which we mentioned in the introduction of chapter one. In the sub-Saharan African region of the Sahel, villagers are apt to use something known as a straw windscreen to shield their villages from the deleterious effects of wind and sand storms. Upon closer examination of this windscreen, it was found to have a non-linear scaling woven pattern that decreased in scale the taller the windscreen got as opposed to white picket fences in the western context that maintain pattern scale across space transitions. The researcher was able to deduce that this African windscreen was a prime example of optimization engineering fractal scaling. The practical reason for the scale getting smaller as the fence got higher at a certain altitude was to shield the villages from gusts of wind. Rather than use up the precious commodity of straw to create a windscreen with a small scale all over, scaling was only applied where it was necessary at the height of the wind. Another rather simplistic example of adaptive scaling was referenced in some of the Yoruba hair braiding styles and techniques. Here, the braiding maintained the same pattern but underwent scale transitions to conform to the head shape of individuals much like UV texture maps of 3D digital models. These are instances of conformal mapping. Given these two examples, designers can start thinking about ways that scaling can be best applicable in for augmented reality 3D UIs in a mixed reality interior layout. [21]

Infinity as well as recursive fractal properties are also controlled by scaling because it allows for the examination and interpretation of a limitless range scales along with the ability to perceive reciprocal feedback loops in space. Recall the example of the stain glass window from chapter one and how the scientist noted that it resembled organic structures of the human body while also showing evidence of being beneficial for human cognition. [27], [7] As the saying goes by sage Trismegistus, "As above, so below, as within, so without." scaling affords perception of these relationships.

It would also be useful in this context to recall the list of the Mixed augmented reality spatial scale frame work listed in the first chapter. While scaling is integral to the function of other fractal attributes these expressions are also modulated by representations existing within figural, panoramic, vista, environmental or global spatial scales or a mixture because each classification has best interaction and visualization practices associated with it. To recap, figural is essentially a first-person point of view while panoramic allows for the rotation of a larger environment. Vista scale is a fixed orientation perspective within panoramic sight with environmental scale only being visible through means of locomotion. Global scale classification requires a map representation to view while map scale projects higher scale forms onto lower scale objects. [30]

The architectural patterns of contrast and levels of scale allow for the individual to ascertain their orientation within any given environment which is important for purposes of navigation and self-identity within the larger context of a design system.

Contrast can be defined as the differentiation between patterns on a single object, building or area of an architectural scheme which provides a visual cue of distinctiveness from which an individual can discern the potential unity of elements as well as different areas of function in a living space. [20]

Scale in an architectural sense is best employed when the inhabitant has a clear sense of the transitions between small and large objects or design features rather than drastic scale changes which serve to throw off the user's orientation sensibilities. Each scale design feature should transition into the next one to create a fluid readable exchange of elements. The goal of most compositions to communicate visual information to the user and any other attendant meanings and employing levels of scale in a gradual coherent fashion dovetails this aim.

The digital media principle of variability is defined as media assets having the potential to exist in nearly infinite variations. Virtual objects are mutable in the sense that the content of a system is untethered from the structure or interface of any program although it does have the ability to be dependent on such things if the design brief suits this purpose. This principle is possible only because of the previous media principle of modularity we discussed. [19]

The fractal attribute of scaling is an applicable design pattern in mixed reality environments for its abilities to aid the user in determining spatial orientation, strategies for navigation, and feature differentiation. The concept of adaptive scaling is particularly useful when designers create media to be used in a wide array of environmental contexts. Readability of certain 3D UI elements in such cases needs to be dynamically adjusted to yield a coherent user experience with the scale-complexity trade-off principle where one can understand the interface and interactivity without having a steep learning curve with each scale transition. Scaling affordances and constraints could be within the context of human factors cognitive reasons to spatial strategy compositions to optimize certain environmental functions of an interior composition. [19], [20]

Recursion /Alternating Repetition /Automation

The fractal attribute of recursion refers to the output of a system or pattern becoming the input for the next stage of the design process. The results are continually returned akin to a feedback loop of progressive refinement. There are three types of recursion which include cascading, which the input/outputs bottom out, iteration which is nested loops within loops and self-referencing which refers to procedures calling procedures. [21]

The architectural principle of alternating repetition seeks to imbue the environment with a sense of flow and rhythm through use of recursive repeating of patterns within already established patterns to generate an organic visual oscillation of elements. When this is executed properly on buildings and interior features, the design stimulates user engagement through visual interest because the design has life, and a structural undulation which supports life as opposed to static banal repetition with no alternation. [20] When speaking in terms of creating an augmented reality 3D UI, repetition of certain process and key function is sure to be employed. It would behoove such compositions to include elements of alternating repetition to engage the interest of the user's visual sensing mechanism for purposes of generating a more immersive experience.

Automation is implemented in media technologies using varying templates and accompanying algorithms. It refers to programed automatic processes within the user interface of any system that eases the user's workload for repetitive or habitual tasks.

For example, in photoshop, people can manipulate photos or create/paint their own artwork therein however, the user interface comes by default with its own set of automated process such as crop, blur smudge pixelate, among many other automatic functions to ease the workload. [19]

The fractal property of recursion presents the designer with a working foundation to experiment with and brainstorm varied types of automation within the context of augmented reality user interfaces for interiors. The first application that comes to mind is for automation to be utilized for repetitive organizational tasks that the user might engage in to select, arrange and manipulate 3D assets within their working space.

For example, within an environment of one's living space, say a person could organize their augmented reality music albums or frequently used applications by either place each asset/icon one by to position spatially or they could use programed templates to organize the assets automatically. This could be based on varying taxonomies inclusive of but not limited to size, shape, color, alphabetical order. Additionally, designers should also think about integrating the architectural function of alternating repetition back into this digital media component of automation to create an array of user interface pattern templates that appeal to the visual sense along with being functional. As far as these templates go, each of the fractal qualities we have discussed are applicable in the design of these templates and should be considered during the prototyping phase. [19], [20]

Infinity/Not-Separateness/Transcoding

Infinity is the property that embodies the rest of the fractal attributes. It allows for the limitless quality of a design pattern's possibility for repetition, expression or length. As seen with some of the fractal principles already mentioned, there exist possibilities for expression in the fractal dimension, scaling, self-similarity and recursion all of which could be in a finite or unlimited range of scales. [21]

The architectural principle of not- separateness embodies the quality of connectedness to the surroundings while maintaining degree of autonomy. Spatially, this represents a building that fits in well with its surroundings not unlike the concept of nested centers and wholes discussed earlier. For architectural or interior features to embody not-separateness, there must be qualities or design elements that connect those things to neighboring elements of the composition to establish a sense of fluency. [20]

Transcoding refers to the translation of media assets into varying formats. It interrogates the computer as well as the human cultural layer resulting in a restructuring of the media assets to conform to the common language of the computer for inter-operability. Video Capture being translated into varying formats to be viewable on a range of devices from smart phones to tablets, TVs and even laptops are one example of transcoding. [19]

The fractal attribute of infinity is an important factor for designers to remember in terms of affording the quality of interoperability in mixed reality layout prototypes. Augmented reality 3D UI elements should be adaptable to variable spatial compositions, user cognitive or aesthetic considerations as a part of the underlying design process. Interior designers should also consider how to construct spatial compositions that embody this quality of infinity to dovetail the inhabiting media forms. Referring to the Lars Spuybroek water pavilion in the discussion of historical precedents in chapter 1, designers can draw inspiration from the smooth and continuous surfaces employed in this interior along with the embedded sensory array. In this case, the interior was smooth to parallel the infinite and continuous nature of the information age with the environment reflecting the prevalent cultural mores of cyberspace and constantly updating media information and technologies.

For example, if an Augmented Reality template were to be installed in a retail dressing room, or a place meant for privacy, it could adapt itself to not include the functionality of surveillance but to fit the needs of the clientele. While in such a place, it could give the customer important product information, availability pricing, etc. If one person's residential interior varied from the next, the interface could adapt its scaling, features and aesthetics to suit these differing environments. [19], [20]

2.3 Spatial Strategies - Overview

It's important to consider the spatial strategies of a design that are some of the core compositional tenants established within the interior design paradigm in tandem with considering mixed reality interior layout organization in terms of fractal principles, digital media and architectural attributes.

We will examine these principles from their native physical context as well as propose insights on remediating these definitions into a digital media context where both can coexist with fluent exchange.

Below, a chart has been culled from I. Higgins manual for interior design spatial strategies which will be followed up by a discussion of the relevancy of each strategy and relationship regarding mixed reality interior layouts. [17]

Table. 2.2

SPATIAL RELATIONSHIPS	SPATIAL STRATEGIES	CIRCULATION STRATEGIES
Space Within a Space	Linear	Radial
Overlapping Spaces	Grid	Spiral
Adjacent Spaces	Radial	Grid
Spaces linked by a common Space	Centralized	Network
	Clustered	

2.3.1 Spatial Relationships

Spatial relationships can be defined as four types of arrangements that allow for two or more interiors spaces to functionally communicate within a design composition. For our purposes here, we include 3D UIs and accompanying digital media assets as part of or an interior space itself. We will take an experimental approach to the design solutions in this category.

These principles are self-explanatory in definition on the physical sense yet digitally, the first way that they can be transposed is through consideration about how augmented reality assets natively can generate these compositions and in what context they could be useful in benefiting the overall user experience. Digital assets can create these interior compositions in concert with physical arrangements through AR projections and appropriate placement on certain coordinates in space. Typically, one space is demarcated or relates to another based on certain functional/decorative boundary features but in addition to these physical objects the virtual can also serve to organize space and lead the user's eye. For example, a completely virtual wall, objects or animations representing a space within a space, overlapping, or adjacent spaces could be created in place or in combination with physical items.

A space within a space occurs when a smaller space within an environment is nested within a larger area. This strategy implies that some quality, object or area is existing within a larger whole, so from an organizational point of view, the smaller should resemble or be related to the larger area to support the overall function of the joint space. The space within a space might also be useful in the context of spatially minimizing and maximizing media asset grids or templates of arrangement acting as a modulator of information relating to the fractal attribute of scaling. Ideally in a single setting, context specific information or media assets should be present in the user's environment, instead of every single element of the UI. Allowing for this relationship affords asset modulation and therefore enhanced user experiences.

Other spatial relationship definitions such as overlapping, adjacent and spaces linked by a common space tie very much into the fractal concept of infinity. As one media item transits from one portion of a spatial arrangement to another, designers should consider what types of transcoding would be necessary to fit within the design affordances and constraints of the neighboring spatial volume. [17]

2.3.2 Spatial Strategies

Second in importance to spatial relationships is spatial strategies which are the strategies employed when organizing space. The terms in this category are self-explanatory however we will go through each to provide design considerations about how these strategies can also be applied for 3D UIs and digital assets.

Linear arrangements are attributed to spaces that require a simplistic straightforward approach to layouts which could take the form of aircraft interiors, shopping malls or a host of other public venues. Media in an environmental space should take a graphical linear format when issues of practicality and simplicity are foremost requirements. For example, it would be useful to put AR projected text that is many paragraphs in length in a linear format either horizontally or vertically for maximizing readability. Other reasons for the linear format could be the simplicity in selecting varying icons in space or understanding where assets are located along a path easily.

Grid strategies are employed when there needs to be a high degree of precision in the functional attributes of a space. Examples of grid layout strategies include the typical workplace filled with cubicles, a concert hall with specified seating requirements among other instances. In these places the grid emphasizes order and structure. Likewise, media assets could potentially follow a similar strategy by using automated templates with varying types or grids to organize icons and user interface elements. Designers might also want to consider implementing a UI design that deviates from this structure and order if the design brief allows artistic license. Equal parts of order and chaotic or random elements often makes for the most compelling and balanced design compositions across all disciplines rather than banal repetition of in graphical digital format of the pre-existing interior scheme.

Both radial as well as centralized are what is known an extroverted versus introverted interior design arrangements.

The radial strategy employs the use of spaces known as spokes in which spaces radiate out from a common or initial starting place. Some airports, sports stadiums utilize this scheme to spatially organize pedestrian traffic in large venues for efficiency. Designing digital media information streams as UI currents guiding users in the pathways of these varying radiations from the central hub would be one possible solution geared towards this layout. Also, since it is such a large and bustling public venue, designers might also want to pay attention to the quality of information suitable for this area along with accompanying cognitive load expectations. Simplified user interface layouts and selection and manipulation controls should have a minute learning curve for ease of accessibility.

Centralized strategies conversely can be attributed to public and private spaces that cater towards introverted or relatively stationary activities. Food courts in malls, Renaissance Italian churches or even some study areas in a library utilize this interior design layout. The user can handle a greater complexity of information in such areas from a qualitative and quantitative perspective as this area are better suited for contemplation. Another design consideration for this region is that if users are going to be stationary for a greater percentage of the time it might be useful to employ the first person figural or rotational Panoramic mixed reality scale designation to make all the contents of the UI available from just a few vantage points without making the user traverse the spatial volume to access augmented reality media.

The last of the spatial strategies is clustered strategy which spaces are positioned in a randomized, freeform asymmetrical or even overlapping configurations as the name would suggest.

This strategy fits best for situations where informality or a relaxed setting that encourages meandering and exploration is required. Best applications for this layout could be a lounge setting, a domestic living room, a retail store that encourages shoppers to explore or even a museum environment. Digital applications and UI elements that cater to the thematic focus of discovery in leisure could be best suited for such locales in addition to 3D assets likewise being staggered throughout the environment to mirror the fundamental quality of discovery of this strategy. [17]

2.3.3 Circulation Strategies

Circulation strategies can be defined as the ways in which the transit pathways in a building are set up to allow for users to navigate the area. Along with thinking about these pathways in a purely physical sense, the strategy could also be applied to the digital objects moving within and inhabiting the space. There are four circulation strategy archetypes which include radial, spiral, grid and network.

The radial configuration much like it's spatial strategy counterpart, allows for movement outwards from one central hub. Spiral circulation strategies lead users along a spiral trajectory along with grid layouts allowing for regimented succinct movements through space. Networked interior layouts, are concerned with how areas within a space can be connected or networked so to speak for ease of access.

Transposing these terminologies into a digital media context, the grid circulation strategy immediately comes to mind in its usefulness to aid the user in mixed reality environments to move, position, rotate and scale media assets in grid coordinate space. In this context, the grid would be a digitally projected superficial overlay over all the environmental components in each interior setting that would be visible only during instances of manipulation if need be. More details on this grid design research concept will be discussed in the implementation chapter.

The radial circulation strategy could be employed from the standpoint of a possible configuration of an ambient UI menu. It could contain radial loops within loops to house varying user interface features efficiently organized and easy to access. One icon could be activated, and other radial functions could emerge from that single action. Additionally, designers could also create radial 3D asset animations in an environmental space as a wayfinding technique to guide visitors in a large public venue towards a certain hotspot attraction.

As far as the network circulation strategy, designers might want to consider the interoperability of certain programs or UI functions as they transit from one area in the interior to the next. What would the nature of adaptability to the spatial, conceptual and cognitive constraints and affordances be for UI and systems layout.

In terms of the spiral circulation archetype, designers might want to consider how to conceptually incorporate the metaphor of a nonlinear spiral into their augmented reality UI media layouts. Spirals typically indicate progression of either backwards or forwards movements through time and space. As far as system controls go in a UI, gestural spiral movements can be utilized to control certain interface elements orientation, scaling or rotation in space. Additionally, spiral design elements can be used as a mechanism to allow user to visually see new media items, messages or assets in que for interaction or conversely functions that have previously been executed. Think of this concept as the mixed reality spiral of life displaying graphically, past, present of future systems of interaction in any given augmented reality digital/physical space. [17]

2.3.4 Summation

We presented designers with a design research framework for organizing physical and digital space mixed augmented reality 3D user interface layouts. Readers were first introduced with the raw building blocks of these hybrid interiors through the fractal archetypes correlated with architectural design patterns along with digital media principles. We utilized fractals as the organizing archetype for these environments for their potential psychological benefits upon the user in addition to naturally intuitive pattern recognition purposes which would be an asset in these multilayered media rich mixed reality environments where organization and readability is paramount.

After introducing the fractal archetype building blocks, spatial strategy concepts were introduced as a means for designers to use these building blocks within interiors spaces. This translates into mapping out spatial relationships and circulation strategies from which the fractal building blocks can be nested inside or work in concert with in these layouts based on thematic goals.

3. MIXED REALITY INTERIOR LAYOUT

3.1 Input/Output Modalities

The setup and overall functionality of a mixed reality 3D user interface is predicated upon the types of input and output modalities utilized. Therefore, these designations should be addressed foremost with the layout and interaction functions following suit. The intention is to provide insight into possible design research paths and to suggest varying input/output modalities for the simulated conceptual mixed reality environment which will be showcased in Chapter IV, Implementation.

Inputs refer to the types of devices or technologies that enable the user to interact with a computer system. Outputs in turn are the devices that display single or multi-sensory feedback from these systems.

Designers can resort to the appropriate device manuals to ascertain the full range of options present but for our purposes, I will be presenting some of the input/output modalities which I have determined through research to be the most applicable to mixed/augmented reality user interface layouts presently. The selections have been determined upon the basis of available technologies, device affordances and constrains along with ease of use. The goal is to present possible input/output options that lower the bar of entry in terms of learning curve along with accessibility for the general population to allow for the widespread proliferation of mixed reality environmental user interface layouts. It should also be noted that the modalities that are being suggested are meant to be used in a hybrid sensing or multimodal sense which means that the system is reading information from multiple input streams and interaction techniques. This works best in a 3D user interface because different situations in an interior augmented reality setting call for varying interaction modalities. Rather than confining the user to one technique or device, multiple is used in accordance with the appropriate context. [25]

3.1.1 Outputs

Mixed Reality Interiors Output Modalities

Table. 3.1

OUTPUT TYPE	PROS	CONS
Head-worn displays, traditional AR (optical or see-through)	+ 360-degree FOR + Portable + Inexpensive + Good Spatial Resolution + Unlimited Tracked number of users in stereo (one display per user	- Physical/virtual object occlusion problems unless combined with scene mapping - Small FOV compared with traditional VR HWDs - Must wear the device - Limited peripheral vision - Weight and cables cause ergonomic issues
External Speaker Auditory Display	+ User does not need to wear any additional devices	-3D sound generation more difficult
Ground – Referenced Haptic Display	+ Can Produce high levels of force if needed + Don't have to wear them + Accurate Trackers	- Limited movement when using them - Safety Concerns
Passive Haptic Display Type – (This is technically both an input and output)	+ Useful when haptics is required for a specific object or physical proxy + Easy to design and use + Increases sense of realism	- Constant for and tactile sensations - Limited by specificity

Above is listed an abbreviated chart of the chosen 3D UI output types to be incorporated into the conceptual mixed reality environment that have been culled from J.

LaViola’s manual for 3D User Interfaces. [25] When thinking in terms of output modalities, visual devices may first come to mind although this category is applicable to the full gamut of sense perceptions. The sense of sight, hearing and touch will be included in this conceptual space to lay simplistic framework however, a plethora of other possibilities exist for designers moving forward.

Both optical as well as video see-through head worn displays are the chosen medium for visual exchange in this space. A head worn display is defined as an eyewear device that enables the user to see virtual imagery either in a purely digital environment or as superimposed 3D or 2D imagery in registration with the physical space.

Video see-through displays are head worn devices with a front mounted camera which is streaming video footage of the actual environment to the user in addition to superimposed digital imagery. The benefits of this option are that users can experience wide fields of view along with designers being able to incorporate enhanced augmented reality registration and calibration strategies. System latency in addition to low resolution rendering of the environment among other issues represent the detracting points of this device

See through optical head worn displays on the other hand enable the user to see the environment though semi-transparent optical combiners while also viewing augmented reality digital media projected onto the lenses which appear to be in the inhabited space. A latency free real-time view of the actual environment, which ensures the synchronization of visual and proprioceptive information is are a few of the benefits of this system. A limited field of view in addition to a higher incidence of graphical registration errors are some of the areas that are in further need of development for this system.

Location specific environmental audio as well as ground haptics which are context sensitive sound and physical vibration are important base components to include in a mixed reality design system because they increase the user's sense of immersion through identification with more sensory components along with providing feedback substitution to the human's sensory system when virtual objects can't be directly touched or experienced as one would a physical object.

Another realm of haptics is Passive Haptic Displays which matches the form and likeness of a digital object with the shape of a physical one that has been imbedded with sensors so that the user can have a real world feeling and visual reference for the virtual object. Passive haptics provides the benefit of this tactile augmentation which increases the ease of interaction and immersion into the mixed reality world while also having a minimal learning curve. Scalability and adaptability of these physical passive haptic feedback props are the main disadvantages. [25]

3.1.2 Inputs

Mixed Reality Interiors Input Modalities

Table. 3.2

INPUT TYPE	TRADITIONAL DEVICE	3D SPATIAL INPUT DEVICE
Handheld Wireless Trackball Device	*An active sensing device that is like an upside-down mouse that the user can hold in one hand to manipulate the user interface	
Game Controller	*A modified joystick with buttons and a touchpad ergonomically shaped to fit the human hand most often used in console video game systems	
Optical Sensing – Depth + RGB Cameras		*Vision based tracking systems utilizing cameras that contain depth and rgb sensors that can create maps of a 3D scene or gestures of a body in space used for tracking
Virtual + Traditional Keyboard	* Standard QWERTY keyboards that can be handheld, full size or	* Virtual keyboards projected onto the surface or visible in mid-air via augmented reality projections
User-Worn + Handheld 3D Mice + Sensor Ring		*Ring supports gesture interactions in 3D, with 6 DOF tracker, may also be equipped with buttons, *3D mice make use of optical and inertial sensing to produce 3D position, orientation and motion information along with buttons and other analog controls
Hybrid Sensing		*This technique combines multiple sensing technologies for optimization of the 3D interaction experience with increased accuracy and decreased latency
Passive Haptic Sensors	*Physical objects of any shape or size with embedded sensors that have a duplicate virtual counterpart	*(repeat)

The input technologies for 3D UIs in mixed reality environments can be divided into multiple categories however, we will discuss both traditional and 3D spatial input for this conceptual space.

Traditional devices can be likened to the common computer input peripherals such as a mouse and keyboard however not all such devices would be suitable in an augmented reality interface.

For example, the traditional mouse or game controller would severely limit the user's ability to walk around and interact within the environment because it requires a surface for interaction. A handheld wireless trackball mouse as well as game controller has been created to compensate for this limitation by enabling users the freedom of mobility. Within 3D UIs, another essential traditional feature is the use of a keyboard and much like the previous description, the standard full-size keyboard suffers from this limitation of mobility. Miniature handheld along with natively virtual keyboards are adaptations that have been developed to approach a solution for is.

Passive Haptic feedback props have been covered in the previous output section, however it's worth noting that they are a physical and somewhat traditional form of input as well even though sizing and shape can vary. I would also suggest an addendum to the established definition of a passive haptics object to include the control of virtual objects and user interface features that don't necessarily correspond to exactly to the shape of the object as in having a digital counterpart. Sometimes, varied forms of environmental control devices are called form and the user should be given the freedom to select from a wide range of input modalities to control their system. This notion could give rise to a new line of interior goods that serve both decorative and function aims.

3D Spatial Input devices provide the system with information about a user or physical object's velocity, rotation or orientation in space and can be further categorized into either being active or passive spatial inputs.

Depth/Rgb cameras are a form of passive spatial input that would be well suited for a mixed reality environment because they are able to take a continuous 3D scan of the interior space and feed the information back to the computer system to aid the rendering system virtual object registration processing ends. These types of cameras also capture user gestural data as a means of allowing the user to use hand or body movements to control the systems user interface. Depth cameras can be placed within the mixed reality environment along with being mounted on the user's see-through head worn display outputs.

One thing that is worth noting about 3D spatial input devices is that they are often lacking in the tactile sensations that a user would experience while in operation of traditional implements. A notable example for this is the mid-air augmented reality keyboard which happens to be under the category of active spatial inputs. For a plethora of human factors reasons, it's most always preferable for the user to experience immediate forms of feedback directly correlating to their actions in both physical and virtual space and the digital keyboard deprives the individual with these tactile and sound sensations. As a result, designers have implemented a technique in virtual environments known as feedback substitution. This is often a core modality to integrate to create a sense of immersion given the absence of physicality in some instances. With the mid-air augmented reality keyboard, designers could utilize feedback substitution by registering sound, accompanied by location specific environmental bass or haptics along with graphical overlays of additional highlights and animated depressions or extrusions in accordance with user's typing. These extra features would enhance the sense of immersion given absence of acute tactility.

User worn sensor rings and smart devices along with handheld 3D mice also comprise the category of active spatial input devices because the user's direct actions influence the input rather than them being indirectly sensed through a passive sensory array. These user worn or handheld modalities are often embedded with 6 degrees of freedom sensors along with buttons that allow for the user to control the user interface with gestures and a combination push button controls. Feedback substitution is also a relevant design implementation for these modalities as well to compensate for the absence of physicality.

The last concept to be addressed as far as inputs go for Mixed reality environments is the fact that designers are not relegated to one type of input within any given space. They are encouraged to make use of multiple sensing modalities to provide the system with the most accurate data to perform intended functions. This is defined as hybrid sensing and enable user to utilize multiple inputs to best suit the interaction task at hand. An example of this could be a combination of an active 3d handheld 3D mouse along with gestural movements of the whole body being sensed by passive depth cameras. [25]

3.2 Mixed Reality Interior Layout

Step 1:

Ascertaining the thematic focus of an interior is the first step in deciding the layout of a mixed reality environment. This orientation plays an important role in determining the overall spatial attributes, along with the look, feel and the physical/virtual functions of the devices best suited for that space. Is the space residential, retail, museum public access, an educational institution, research laboratory or corporate workplace? Answering this critical question will give the designer initial parameters to draft a functionality and aesthetics framework for the interior. For instance, the design aims of a mixed reality residential interior or research lab would differ from a public access spaces most notably in the fact that the designer would tailor the public space to have less specialized functions of interactivity. Users perusing public space interiors have generally less time to devote to learning how to interact with a new interface. The amount of user interface options along with the learning curve to utilize the system should be kept simplistic to enable a low bar of entry. Conversely, in less public spaces, users can allocate greater time and mental resources towards discovery and interaction training. In a lab for instance, specialized tools enabling precise interaction possibilities would be beneficial whereas general gesture-based selection techniques or simple passive haptic feedback objects would be more suitable in a public space for ease of usage.

After this general classification has been decided, the designer is then able to work with a more pointed theme based upon the client or venue's goals for the space which will affect how the virtual and physical environment is constructed to suit these aims. Despite the variance in these objectives, one underlying theme is that mixed reality spaces should mirror the essential quality of the people and information flowing through them. Surfaces in these interiors could mirror the inhabiting digital media forms if they were made to be, biomorphic or resembling nature. In this case, augmented reality media forms are like the cells in a blood vein or a water stream of a river. Mixed reality interiors in turn could be constructed to embody this smooth and continuous core quality of their essential nature which would lend itself to the creation of more immersive, easy to understand environments with enhanced user experiences. Designing an interior in this manner goes in accordance with one of the fractal building blocks of mixed reality environments mentioned in the previous section. It embodies the fractal quality of infinity, the architectural principle of not-separateness in addition to the digital media function of transcoding which deals with the translation of media assets from one format to another. For our purposes, the digital is getting translated to the physical and vice versa, and in order create a fluid language of understanding between these two realms, similar continuous biomorphic forms constructed spatially and virtually would be an ideal intermediary element for base aesthetic considerations. In addition to simply establishing a fluency on the design front, restorative and positive emotional responses are an added benefit of utilizing such biomorphic construction approaches as some cognitive researchers would note. They have concluded that human users have a mental processing system which is positively receptive to certain patterns of natural stimuli in their environments. This also includes artificially simulated natural stimuli in the case of art or structural patterns of sequences in media simulations or the built environment. This is a topic discussed as one of the potentials for further research in chapter five. [26], [24], [23], [22]

Step 2:

Once the public or private, commercial or residential classification along with the thematic focus of the environment has been decided, now is the time to concept and rough out the basic shape of the interior along with its zones or spatial relationships of activity in addition to interaction methodologies for the user to acquire spatial knowledge.

If this were a mall type setting, the orientation is public, and the general theme would be shopping and leisure. There would be areas demarcated for travel, dining, special events along with public rest and utilities. At this point it would be useful to apply the information already presented about spatial strategies and the fundamental building blocks of mixed reality environments to organize the space in terms of thinking about the variability of this area and scaling fractal properties and spatial relationships along with circulation strategies. These two properties, along with spatial strategies enable a user to gain a sense of location and orientation in an interior along with impetus to travel around and discover elements of the space. Designers should refer to the spatial strategies in chapter two as a guideline for concepting the physical/virtual relationships and strategies of their space in development. [17]

With the example mall environment, designers should consider the virtual as well as physical means that would entice a user to patronize certain establishments in accordance to their needs as well as swarm augmented reality animation sequences and virtual scaled maps of the interior to help the user with virtual/physical navigation.

In 3D interface terminology, a scaled version of a map or hybrid virtual space that users can interact with is called a world in miniature and this implement would be useful for the user to understand their location from an exocentric or third person point of view. This is especially ideal in large environment navigational schemes where the user is not able to gain a broad sense of the possibilities of the interior from their normal first-person or figural spatial perspective. This represents what is known as survey knowledge acquisition which is the most ideal form of spatial information acquisition in some instances of interaction where it’s important to acquire a full scope of the area. It involves map like knowledge of an interior, which consists of object locations and orientations along with inter-object distances. [25]

In other instances of augmented reality 3D user interface interactions, taking the opposite approach could also beneficial to aid the user in efficiently locating a desired location. Rather than having to study the entire map with survey knowledge to achieve the same outcome, users entering an establishment might want to be guided directly to their destination from an egocentric or first-person perspective via landmark or procedural spatial knowledge. Landmark knowledge allows for users to identify and navigate within hybrid environments via recognition of textures, forms and sizes while procedural knowledge relays a sequence of steps or actions to the user to allow them to find their way in a route like fashion. Given the background knowledge acquired about the nature of swarms presented in chapter 1, applying some of these organizational methodologies for directing attention could be an interesting starting point as a navigational strategy when utilizing procedural or landmark navigation wayfinding strategies. [25]

AR digital assets within a mall spaces could gradually build a trail along circulation pathways to the desired retail location while a few of the navigational media items could purposely veer off the intended trajectory. This could open doors of possibility for the user to explore stores or venues of a similar nature to offer up perspective and variety of more choices. For example, a group of hungry teenagers enter a mall establishment seeking a specific pizza restaurant in the food court. The augmented reality navigational array leads the group to the eatery via graphical visualizations of molten tomato sauce lava and dancing pizza slices. However, along the way, some of the anthropomorphic pizza slices veer off course to a comparable pizza establishment located within the vicinity. The user has clear directions to their intended location along with a clear understanding of potential alternatives. In this instance of procedural knowledge, the user was able to acquire specific points of knowledge about the environment relevant only towards their intended function rather than about the whole space making the user experience more efficient.

There exist two types of swarm intelligence/organizational schemes as noted in chapter one, direct and indirect recruitment strategies. The above example made use of a direct recruitment strategy using the simulated graphical pheromone signature of the molten sauce along with swarms of pizza slices following in suit. This type of mixed reality visualization could also be utilized by certain retail locations to run promotions or sales to attract patrons using similar tactics with other developmental possibilities being vast. [14]

In a similar scenario, an instance of landmark knowledge could be applied by having one of the pizza slices dance in the direction of key landmarks for navigation like the dance of a honeybee that communicates wayfinding instructions to other bees in the swarm to food sources. This is an example of an indirect recruitment strategy that users could engage in to find their way around an environment.

Both recruitment strategies along with all three spatial knowledge acquisition methodologies have their merits and it is the endeavor of designers to test out and harmonize these elements within a mixed reality environment to suit compositional objectives.

Touching briefly on spatial strategies layout a mall environment in this example would most likely be suited for either a linear, radial, or even spiralized dominant spatial strategy with individual retail locations embodying a clustered strategy to encourage exploration and discovery while the circulation strategies could be of any orientation to best suit the design aims. The same previously mentioned guidelines in chapter two for these spatial strategies can be applied. Spatial forms and augmented reality media alike need to be modulated and responsive in accordance to its orientation in space and user affordances and constraints of that region. Another concept worthy of restatement is to incorporate the methodology of nested centers and wholes while drawing out concepts for these hybrid spaces. In the mall example, while all the retail locations might differ in products and services, how can the designer construct the essential qualities of the space and augmented reality media simulations such that the user can understand that they exist within the same ecosystem? How can they work together compositionally to support the overarching thematic focus of the mall environment? This would require creating a common language for digital along with physical user interface elements. 3D user interface menu items should interact in similar ways from region to region along with the smooth and continuous physical space embodying certain characteristic spatial features that are self-similar while also embodying key elements of differentiation while transiting through various levels and scales of virtual and physical space.

Step 3:

During the conceptual phase of 3D interfaces for mixed reality interiors, it's crucial to decide upon some basic input/output modalities that will enable a user to function effectively in the environment. Context, purpose as well as public or private orientation determine what types of specialized devices are needed for the user and interior.

For specifics designers can refer to the full list of device recommendations and considerations for mixed reality interiors mentioned in the first part of this chapter. However, a few core implements are necessary for each hybrid environment to function which include rgb/depth sensor cameras, mobile head worn displays, and handheld or user worn controllers along with speakers for sound and portable environmentally placed haptic feedback devices.

User-worn or hand-held controllers endow the user with the ability to control media elements in the 3D user interface such as the selection, manipulation of certain functions or tasks. A handheld 3D mouse with buttons and sensors would suit these interaction goals at the most basic level, however, 3D user interfaces are often best suited for multimodal input and selection tasks. Multimodal refers to a variety of input streams that feed into the system along with interaction modalities being used to engage the interface. This gives the user freedom to utilize many different interaction methodologies best suited for each task at varying mixed reality spatial scale transitions rather than being pigeon holed to one.

Displays refer to the devices that deliver feedback to the user in the form of visuals, sounds or vibrations. Within a mixed reality setting, the user-worn displays are essential for visual feedback as well as speakers for sound and haptics to stimulate a sense of touch. When operating in a mixed reality setting, designers utilize these display modalities beyond their ordinary function for purposes of feedback substitution. In virtual/physical environments, users are often not able to experience life-like sensations and feedback from interacting with digital objects and this detracts from the sense of immersion into the hybrid world. To compensate for this inadequacy, feedback substitution is utilized for the display modalities to enhance the user's sense of presence and action in the space. [25]

For instance, if the user selects an icon in the 3D interface, the system will provide visual feedback of a highlight, a sound along with a haptic vibration to indicate selection. Since icons in the menu are solely digital, the user cannot reach out in the traditional sense to activate its function. Providing feedback substitution in these types of instances begins to address the issue of the dearth of feedback from not being able to interact with digital items as one would with the physical.

Within these virtual/physical spaces, depth sensors placed at varying points in the interior allows for the computer and rendering system synched with the user's display modalities to take a 3D scan of the environment continuously which could aid in solving occlusion and registration errors for head worn displays. This could also potentially cut down on hardware bulk that the user would be burdened by. In some current systems, depth sensors are already included in AR eyewear devices and this is beneficial when operating in outdoor or variable terrain that has not been optimized for mixed reality experiences. Though, the mixed reality workflow being proposed here aims to streamline the user experience by keeping interactions as naturalistic as possible. Wearing heavy or unwieldy objects to operate within mixed reality works contrary towards the ideal. This translates into the utilization of user worn devices that perform their intended function while also striving towards minimalism. In an ideal scenario, the sensor cameras could be embedded into the environment as well as the head worn displays to create optimal augmented reality interaction results however, current technologies and human factors issues must be considered. This would include the ratio of benefits versus detractors as far as human comfort for prolonged usage might be. These are topics beyond the scope of this research project but are nevertheless, helpful for designers, developers, and researchers to consider moving forwards in producing iterations.

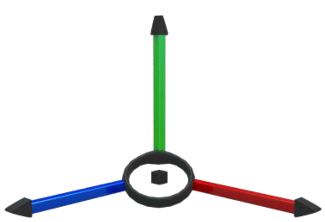
Beyond these core input/output devices, other mixed reality environmental interfaces might call for more specialized manipulation or selection tasks and there are according implements that would be optimal for this. For example, an artist, would benefit from a stylus to draw or sculpt with or it might be more natural for a user to control user interface elements in a domestic setting by utilizing passive haptic feedback devices which could take the form of everyday homewares and soft goods such as pillow and blankets being embedded with sensors.

3.3 3D User Interface Core Components

3D user interface components will broadly vary dependent upon the purpose of the interior, the spatial layout as well as customized user settings. However, a default interactions menu housing the main functions present in all mixed reality settings will be addressed which I term as the Mixed Reality Globals.

These Globals can be accessed by the user fully in domestic environments and by the facilities managers in more public venues with patrons or visitors in these settings being locked out of certain features. For instance, a store manager, may have a set mixed reality spatial layout in their storefront for users to interact with when patronizing the establishment and they don't want to have objects altered, deleted or moved around as this would ruin the display. As a result, shoppers would be locked out of the manipulation controls in the globals.

An outline concept of the main interaction component settings that could be included in all mixed reality environments include:



Universal 3D Manipulator Widget

This icon appears by default when either a group or single item is selected via the designers chosen selection modality. This could include ray-casting selection or gesture actions among other modalities.

Mixed Reality Globals Icon

This icon appears as well when the user first selects an object and it houses the full gamut of default user interface features in the following paragraphs.

User settings Profile – allows for the user to control graphical, sound, and haptic display response levels along with other customizable functions relevant to the purpose of the space, also indicates the amount of allocated hard drive space for the user and the system

Sharing – user can share, email, instant message or send varying messages, objects, programs or functions to another individual in a mixed reality environment, social media or on a mobile device

Recycle/Delete – the ability to dispose of certain apps and icons, templates, sounds or any elements of the interface

Save/Archive + Install/Uninstall Apps – able to store and save varying elements of interface or install/uninstall applications

Spatial Asset Templates + Installed Programs- default or user created templates for media assets of UI icons in the spatial layout of the interior, selections can be made for a section or the whole environment, this is the area where either the user or designer has access to the World in miniature which is a smaller map like virtual representation of the interior used for asset manipulation or application designation purposes. Templates for media assets can include any shape or configuration of arranged virtual items such as music, video, application shortcuts or much more that are maximized in a user's space for easy access. These templates are an important organizing element in mixed reality environments to enable the user to navigate, automate, customize and ultimately optimized their personalized user experiences.

Spatial Locks + Linking - user can lock or link certain functions or assets being manipulated in a zone or the entire interior space

3.3.1 Functions

<u>Mixed Reality Globals Menu</u>

This menu set is executed in figural space and contains both 2D and 3D elements of spatial interactivity. When the user first

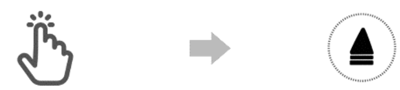


Fig. 3.1

selects an object or a group of items, the manipulator icon appears initially but they can also push a button on one of their user worn 3D spatial input devices to activate the Mixed Reality Globals function. This icon pictured above as the triangle can then be selected by the user with hand gestures.

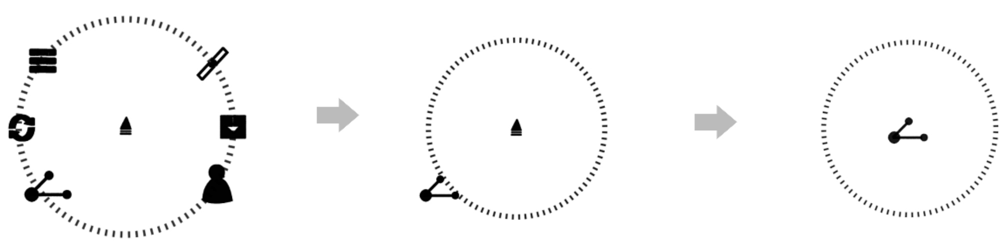


Fig. 3.2

1. Once the MR globals button is activated, it minimizes slightly into the center and pops out the main menu with all the default 3D user interface options. Details for each function were listed in the previous section. These figures will follow the path of just one of the options which is the share widget to demonstrate the interactive process. In the figure above, the user selects the share widget and then the icon transitions into the center of the interface.

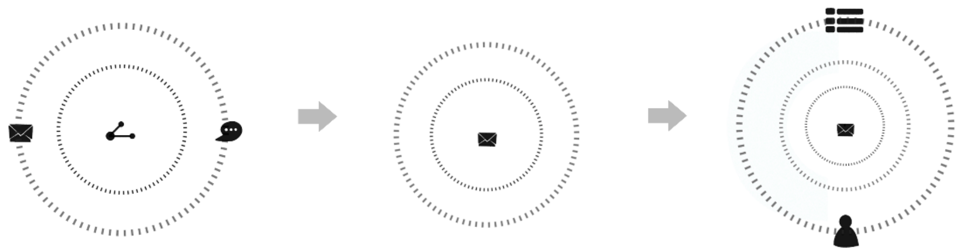


Fig. 3.3

2. An additional ring expands to reveal two additional applications nested inside. Sharing in the mixed reality context can mean attaching media items to send to another individual or sending messages just as one would on a computer or smart phone. In the figure, the email icon is selected and then it transitions as well to the center of the interface and then pops out another ring revealing more options to select contact in addition to a menu for mail settings.

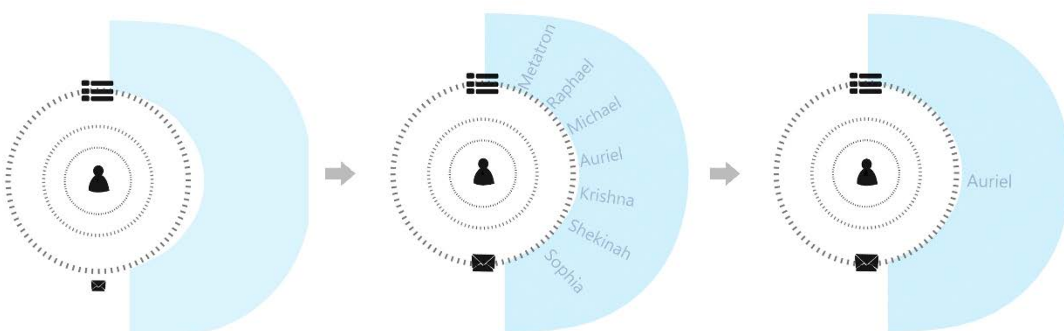


Fig. 3.4

4. The contacts icon is selected and then it moves to the center of the interface followed by a half circle semitransparent ring rotating out from the interface that reveals a list of names.

The user chooses one of the names and then the half circle disappears again to indicate it's been selected.

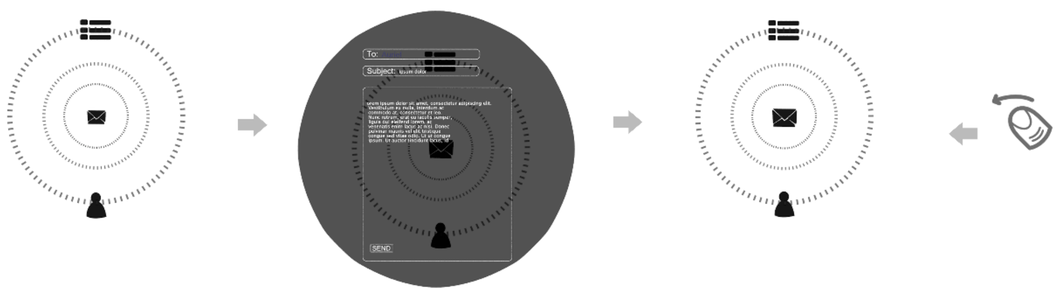


Fig. 3.5

5. Now that the user chose the contact Auriel, the mail icon activates and returns to the center of the interface followed by a widow maximizing to allow the user to type a message via their mid-air virtual keyboard. The user can also include any other attachments they wish to send. Once the message is sent, the window minimizes and then disappears to reveal the three expanded rings with the icons attached at the highest rung. The user makes an inwards swiping motion and it collapses the menu on the highest ring to reveal the one previously selected beneath it

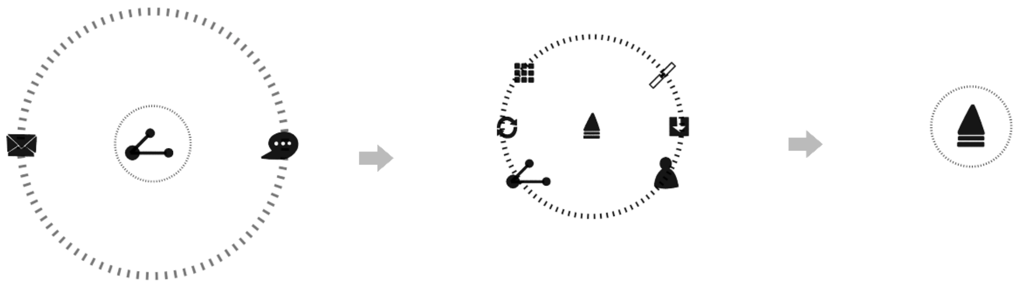


Fig. 3.6

6. An inwards swiping motion is continued until the user interface returns to the base MR globals icon that way displayed initially.

This MR globals menu walkthrough sequence demonstrated how a user can navigate one possible layout of a 3D user interface menu for a certain function. This is an example of scaling the interactivity of the interface back to a more 2D approach because the interactions in this figural spatial scale context were best suited for this modality while it embodies the 3D presence in graphical features in habiting real-world space along here. Other salient features include nested graphical rings of interactivity and self-similar interactive features across the range of scales as one traverses the menu settings. From one selection to the next, the user can quickly familiarize themselves with basic functions of the interface for easy navigation. Also, this layout adopts more of a holistic approach to interaction with UIs instead of a linear modality. Dependent upon the number of rings present in the interface, the user can determine where they are in the menu system at a glance and navigate to other setting easily by selecting one of the rings in the trail of circles to have it maximized immediately. This eliminates the necessity of the user having to successively hit back arrows which one would have to do in a linear layout.

Manipulation + Selection

Selection and manipulation in mixed reality user interfaces is multimodal in the sense that it affords the user multiple techniques of interaction within any given session. How one interacts with virtual and physical space weigh heavily upon the initial input modalities chosen for interaction within the interior. The input/output devices outlined in the previous section are all viable choices for operating within a mixed reality setting however in the below example and figures the inputs utilized to demonstrate these interactions include:

- A smart ring and bracelet equipped with gesture sensors, buttons, and ray casting functionality
- Depth cameras in the environment and on the user's heard worn display to pick up on user's body movements and gestures

A panoply of interaction techniques exists and have yet to be created for the various types of applications that could be created in these hybrid environments. However, this section will be limited to what I term as agnostic mixed reality selection and manipulation modalities. Within these interiors just like having mixed reality globals, the user should possess a basic means of selection and manipulation of digital assets along with the ability to open the settings menu and execute basic functions. I will go into further details in chapter four section 5.2.2.1 about the discovered research potentials of this multimodal selection and manipulation technique that is outlined below in the figures and text. The following is a test environment constructed out of a plane and cube or rectangular foreground and background objects to showcase these interaction modalities.

1. AR Soft Selection - Null

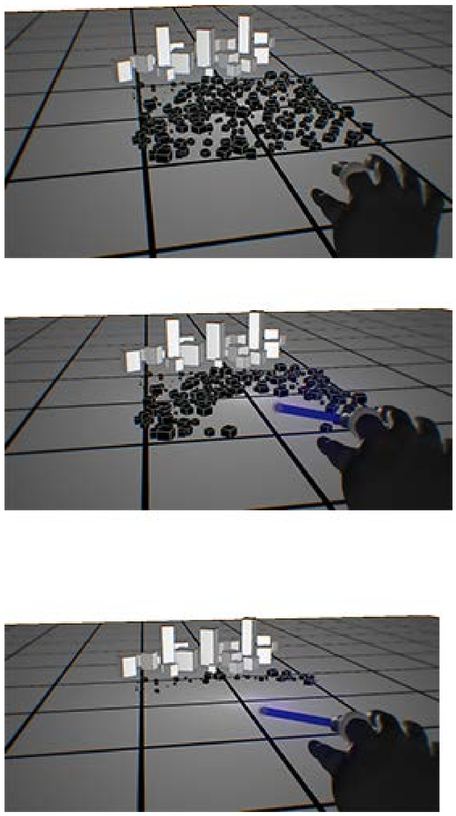


Fig. 3.7

In this setting we have geometry in the foreground as well as the background along with the user being equipped with a smart ring in addition to the rest of the previously stated inputs that make this interaction possible.

A ray-casting beam is projected via the user's pointer finger and this selection type acts to soft select null the objects within its volume from being manipulated by making them invisible.

This is an adaptation to the traditional volume-based point and selection techniques utilized in 3D UIs such as the flashlight, aperture selection or sphere casting. Each of these processes utilizes a volume in space that can be expanded or contracted to select multiple objects at one time. For this demonstration, a soft select sphere volume is used to null the foreground objects. Having this type of selection technique is important especially for media rich mixed reality interiors because often foreground assets may occlude background objects that the user wishes to select. Nulling objects through volume selections allows the user to efficiently complete this task.

2. AR Soft Selection

Soft selection can also be applied in the established way for volume selections in 3D UIs however the technique presented here allows the user to engage in two different functions after the initial group of objects in selected. First, the group of assets is selected with the spherical volume soft selection. What initially activates is the 3D manipulator widget by default to allow the user to scale, rotate, translate the items in virtual/physical space. By hitting another button on the user-worn smart devices, the mixed reality globals icon appears and can be activated with more settings becoming available about the selected objects. The MR globals enable the user to delete the object cluster, share it, lock it, arrange them in an organized pattern in space rather than haphazardly placed among other options. The full list has already been addressed in previous sections of this chapter.

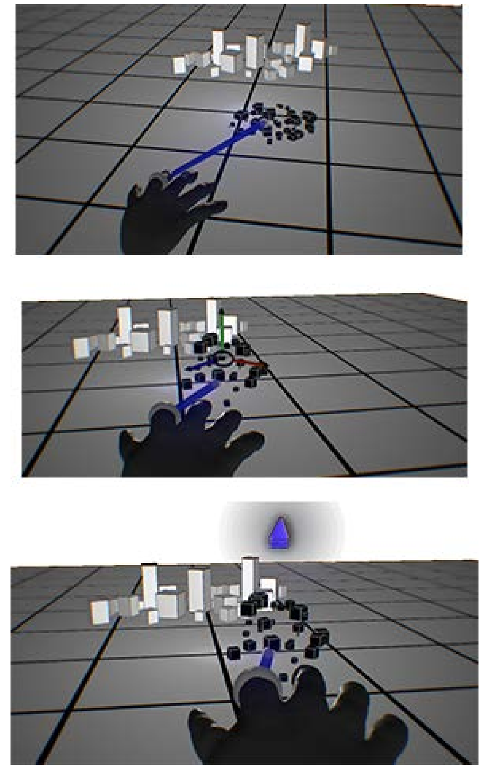


Fig. 3.8

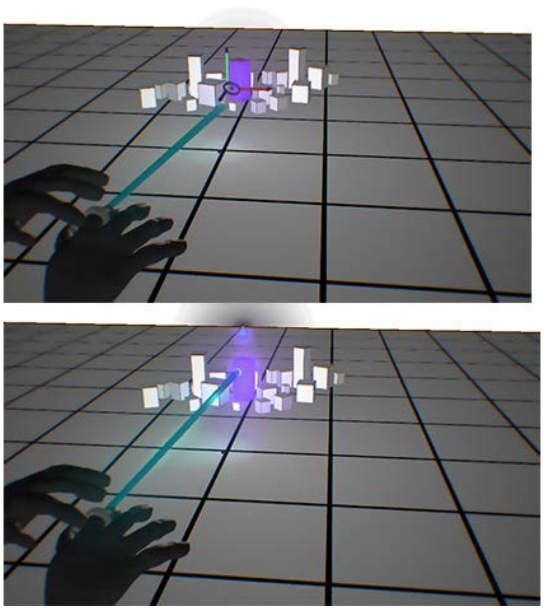


Fig. 3.9

3. AR Single Object Selection

This is the most simplistic modality of selection for single media assets in space. It utilizes a ray-casting technique that highlights a single item once selected and then the user is presented with 3D manipulator widget the same as in the example above along with the Mixed Reality Globals options menu.

5. AR World in Miniature

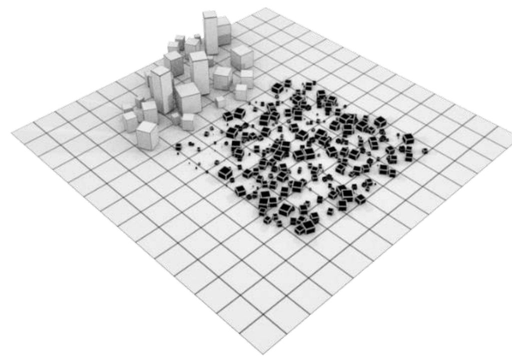


Fig. 3.10

The world in miniature is a well-known technique in the 3D UI paradigm which is a small version of the larger environment the user is nested within. In video games this is typically utilized to endow the player with survey knowledge or a map like understanding of the environment. For mixed reality interiors, this same technique can be utilized to allow the user to efficiently select and manipulate virtual assets in their environment via this miniature virtual duplicate without having to be near those assets by traveling in space. This world in miniature is a nested function of the spatial asset template icon in the mixed reality globals menu. Selections could take place in this virtual duplicate utilizing mainly gesture point and select types of actions much like those utilized on tablet or smart phone devices to minimize or maximize the world in miniature, highlight select objects and use the pointer finger to move objects around directly.

6. AR Clear Selected Items

After the user has finished with all their selection and manipulation tasks, they could make a simple passing gesture over the hand equipped with the sensor ring to clear all selections. In most interactions scenarios, a user should be endowed with the ability to deselect objects at will and this technique affords them this opportunity. The first figure is the hand wave and the next figure show the environment reset along with the ray-casting pointer retracted.

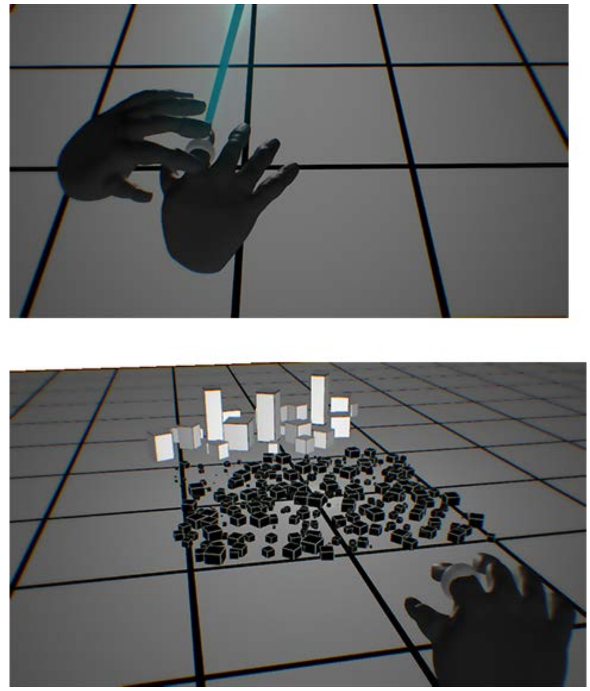


Fig. 3.11

3.4 Asset Gradients + Modulators

In chapter one precedents, we learned that one of the earliest instances of digital media in an architectural sense were billboards, electronic signs in retail spaces among other venues. [1] These displays were static mobility, structurally and content wise and were either always on or off. Transitioning into the realms of augmented reality 3D user interfaces, designers are now afforded the opportunity to move beyond one-off types of applications for augmented reality by creating interface ecosystems around such programs and accompanying media assets. Part of creating and effective mixed reality interface is including the aspect of gradients as well as modulators to control them.

Gradients in an augmented reality refer to the quantity as well as type and quality of virtual media present in an environment. A few types of virtual media could be a specific programs or applications, movie, music or a collection there of. Gradients of these items could refer to where they are placed in space, in what quantity and quality and modulation refers to how the user or automatic components of the system organize these media stores. For example, within a traditional computer system, a user does not have all their programs and drive windows open at the same time as it would clutter the user interface along with causing chaos and confusion. The same line of thought applies to virtual items in an augmented reality setting. Therefore, a whole host of user interface storage, folder and minimization options are available to modulate the media on a computer

A sound method to determine where assets should go, and the gradient threshold is to use the interior's spatial strategies, the Mixed Augmented Reality spatial scale framework, thematic purpose and the finalized layout of the space. [13], [30] From this starting point, designers can determine which areas in physical space would be most suitable for certain items and then set an interior's customized brand of gradients from there. Due to the variable nature of each mixed reality setting the gradient layout of each interior will vary however, general suggestions for the placement of gradients can still be derived from the general analysis of the spatial design, relationships, strategies and circulation patterns.

Modulators will also be variable in each interior space in accordance with the space's aesthetics and interaction goals. Although this variance will only be on a superficial level in regards to graphics or interactive animation differences.

Despite these stylistic variations two main types of modulating elements exist which include fixed or location specific as well as mobile modulators. Beyond these two modulator archetypes, a third exists which in nested inside of the fixed and mobile types which I term as miscellaneous. These secondary modulators include organizational functions operating based on user preferences, favorites, alphabetic or numerical order among other classifications.

3.4.1 Gradients

Digital Media Asset Gradient Chart

Table. 3.3

DENSITY	QUALITY	QUANTITY	SPATIAL VOLUMES
DIFFUSE	*Email alerts + brief messaging + Status updates *Basic Maps for directions *Abbreviated Menus for drinks or food *Performance Itineraries *web access but optimized for diffuse setting	UI elements simplified, optimized for facilitating only the dominant activity of the space. Media assets and information low in volume	*Performance + Sports Stadiums *Hallways or Circulation Pathways *Nightclubs + Lounges
INTERMEDIATE	*Interactive gaming, exercise or social media applications *Detailed Menus + Product descriptions *Web Browsing *Email + Messaging	*UI elements + media assets and information endowed with medium complexity *Relevant to providing pertinent details about products, artefacts, menu offerings while encouraging additional explorations	*Museums + Cultural Institutions *Malls + Shopping Centers *Residential *Café + Restaurant *Gym *Children's play zone
CONCENTRATED	*Interactive AR Programs for Science, technology, computer graphics, and mathematics *Web Browsing *Literature + Research Journals *Word Processing *Email + Messaging	*UI functions and elements with the greatest complexity Gradient is situated in spatial volumes where the user can experience the greatest degrees of focus and concentration to mull over options, study, research, explore and consider multiple possibilities	*Public Library *Classroom *Research Lab *Office/Study *Workplace

In table. is listed a general media gradient applications chart for mixed reality interiors UIs based on location or spatial volume type ranging from diffuse to concentrated densities. These environment types encompass a medley of interior design layouts, yet it is ultimately the spatial strategies employed in each of these spaces that determine the dominant media gradient concentration. Although, it is possible for a single environment to contain all three density types across the layout of the building.

For example, a sports stadium could contain circulation pathways along the perimeter of the building and stadium seating areas in addition to a Café for patrons, an annexed gym for the athletes along with work offices for corporate employees. The dominant density of this sports center is still diffuse because it mainly caters to the patrons yet throughout the layout of the structure all densities are accounted but some to a lesser degree. The areas where the sports fans will be situated will be diffuse with the associative user interface qualities of simplification of the menu selections as well as presenting information that does not require sustained attentional focus. The purpose of the venue is a social outing, and to enjoy the sports game. Making the mixed reality media gradient diffuse in this area ensures that the 3D UI is simply augmenting the occasion for users, not occluding with weighty options and details that would require much thought.

The area of the stadium relegated to the augmented reality gym for the players has an intermediate media gradient. Users in this area would be in engaged in AR applications catered towards exercise and fitness and would be able to devote more attention to media elements or menu items presenting options for features such as a virtual obstacle course or personal trainer among the exploration of many other possibilities.

The office portion of the stadium features a concentrated media gradient with corporate employees at work and in need of the appropriate functions to get the job done efficiently. In this case, this space presumably would cater towards marketing, business analytics among other operations and professionals focused on their endeavors would be able to intake more complexity and a steeper learning curve for the mixed reality user interface.

The density can refer to the quantity of certain applications as well as the complexity of interface options and interaction techniques available in and environmental 3D UIs. The composition of media densities can be homogenous or variable. For instance, one gradient could contain a collection of music while another on the same density level could contain music play back in addition to video recording, gameplay or drawing/design related functions.

Fig. 3.12

Diffuse(Right) and Concentrated(Right) Intermediate(Middle) variable AR media asset cloud densities

3.4.2 Modulators

Modulator Chart

Table. 3.4

TYPE	ORIENTATION	ATTRIBUTES
Spatial – includes Area/Volume of space/Contours/Surfaces (Physical)	Semi-Fixed/Location Specific	This modulator can be variable in terms of function and graphical aesthetics however it is site specific within the context of an interior setting and is fixed to wherever it is placed and is visible to all users of the space unlike the personalized swarm entity modulator This modulator is tethered to the environmental space it inhabits and can adapt its UI elements to conform to the structural features of that space by scaling, rotating or adjusting other content parameters to yield an effective user experience. Although the virtual spatial modulator is fixed, it can still be dynamically altered and adapted to changes within its situated environment. Spatial is a modulation attribute with certain digitally visible media implements that are integral to the user interface specific only to a region in the interior. While how it operates to modulate media gradients of that space is more of an interactive animated process.
Swarm Entity – any shape, thing or geometric form (Virtual)	Mutable/Mobile	The Swarm entity is an augmented reality miniature or large animated modulator that is made up of the user's coalesced personal media assets and can take any humanoid, creature or abstract geometric form. This swarm entity modulator could both be set to stay in a certain location or accompany the user around in space like a virtual personal assistant of augmented reality smartphone. It could potentially house user interface access to one's contacts, messages, online media accounts, images, music video or virtually any digital media item while a user is on the go. Aside from being specific to each user, swarm entity media asset particle arrays or animated light trails can be utilized for wayfinding strategies in large public access spaces or to run promotional campaigns by certain retail locations. In this capacity, users, swarms can be utilized for navigation or by retailers to advertise by means of virtual trails of offers or coupons leading up to their brick and mortar business.
**Misc. Classifications – ** User favorites, alphabetic or numerical order, etc. (Virtual)	Nested within mutable or fixed orientation types	Within the swarm entity and spatial UI modulators, the miscellaneous classifications further modulate the media and interface elements in accordance with the user's preferences or set design thematic templates for the mixed reality space.

Mixed Reality media asset modulators can be interior specific, fixed or mobile and personalized to an individual's custom AR user interface. Spatial Modulators are fixed to a specific area of an augmented interior and comprise an integral part of the aesthetics of the interior's ecosystem as they modulate the gradient of user interface complexity and asset density in accordance with the room's spatial strategy affordances.

The purpose of the spatial volume is to dictate the expression of this modulator function. For example, as a user is entering an augmented reality clothing store, there might be augmented reality displays detailing information about new product arrivals, promotions or sales scaled large at the front of the store. However, as the user transitions to the back of the store the gradient of scale and quantity of these displays diminishes to being small and inconspicuous price tags with product information extruding out from display stands. In this example the advertising display banners utilized the Spatial modulator because their media gradient had been modified in accordance with where they were placed in space to account for the area's design goals and spatial strategies.

On a domestic front, spatial modulators could be used within the context of the menu system alterations when transitioning from an office/study to a hallway. The user interface within the office would have a higher media gradient of complexity and options than when the user goes into the transit pathway where the interface might be optimized for simplicity based on the cognitive constraints of a user already being engaged in the activity of walking. The is another area ripe for more user study tests, however these basic designations prove useful during this initial prototyping phase.

Spatial Context or Location Based Modulator – (Immobile)

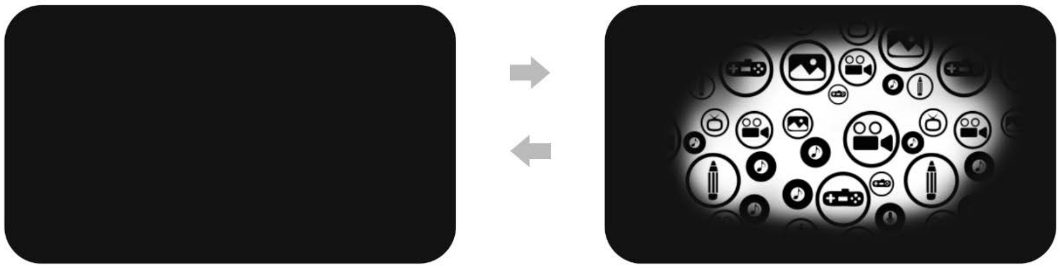


Fig. 3.13

Spatial Membranes, closed (left) and semi open(right) make up volumes of space or physical items/architectural features of interiors acting as digital media asset particle modulators like the swarm entity. However, it has a more permanent immobile quality as it also serves to define the spaces physical as well as digital volumes. For example, in a living room with wall or spatial feature membranes, they can be either closed showing the user no media or partially open allowing some of the user's media assets to decorate the setting as ornament in one respect but also containing inherent functionality. When it opens to display the media assets, they are not confined to the wall space but are 3 dimensionally augmented and can occupy any space in the room 2D or 3D. If the user wanted to display picture frames of family on the wall, for instance they could summon them up from the wall's selectively permeable membrane and position the images somewhere in the room. Besides these frames serving as decoration and nostalgia, they could also double as a messaging or communication beacon with that individual along with housing any additional contact information.

Swarm entities are the mobile types of gradient modulators and this form of modulation is especially relevant when a user transits outside of their domestic or familiar customized mixed reality environment that has already been setup with the static spatial modulators. It affords the user with the ability to enter different mixed reality interior layouts and still retain some of their personalized functions much like a smartphone device except in the form of an augmented reality companion of sorts.

If the user purchases or adds to their media collection, the correspondent entity will grow and pulse a radiant glow on that section of their body as an indicator of a recent edition.

The swarm entity is mobile as is can move, jump, flip, fly, glide or perform kart wheels. around the user's interior space to visually indicate certain status messages or interactive functions. It can also disperse itself or maximize and minimize at the user's behest to build digital media structures for ease of access to interactive content. For example, if the entity's sole purpose is to house their musical collection, instead of a physical album shelf, the being can construct an augmented reality one on the fly wherever you summon it and will stay expanded until you ask for it to contract back into its mobile form to perform other tasks if need be. Albums will appear on the walls or in the thick of the air before you to choose from.

The Swarm along with the site-specific modulators in service to spatial scale classifications can also serve as the interior's principle Augmented Reality choreographing element. As mentioned in chapter one's background and literature survey, AR/Mixed Reality lacks strong principles for organizing space and directing user's attention as it's currently a relatively new medium. Unlike traditional multimedia, film or animation, which can borrow from the cannon of cinematography practices, AR is playing and interactively immersive from all angles. While the scope of this research project does not include how to direct augmented reality films, utilizing the swarm modulator to move across space and direct the user's focus to interface features requiring attention could be a potential useful function of these types of modulators beyond its proscribed purpose. It is also worth noting that a user can have more than one swarm modulator to suit their preferences for virtual media gradient modulation.

Below is picture a few stylized figures to demonstrate some of the potentials of these modulators. The icons used represent a few of the potential media programs and assets that comprise the gradients and are controlled by the modulation functions.

Swarm Entity Modulator – (Mobile)

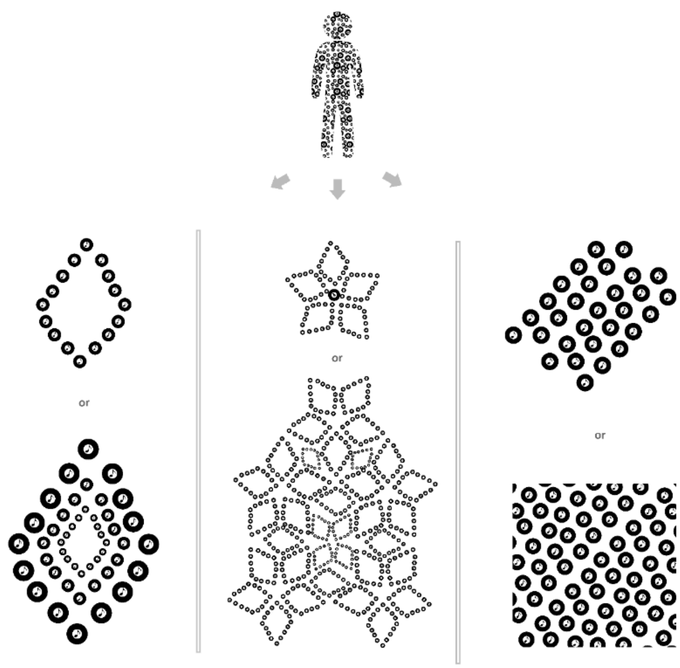


Fig. 3.14

Swarm Modulator(above) and a few potential media asset dispersion variants in the three columns below. The image of the dispersion above is simply a stylized abstract representation. Although the above representation is humanoid in form, it can take on any representation or even an abstract geometric form in its condensed mobile format. It's primary function along with the site specific spatial modulators is to modulate the media asset gradient threshold of the user's interior space in accordance with their desired programing. It would not be ideal to have every single digital media item expanded all the time as it would contribute to sensory overload and would violate the Zen View pattern language. This principle as outlined by C. Alexander states that beautiful views should be constrained not spoiled by large gaping windows that would decrease the overall impact and vitality of the setting. Although he was referring to a simple home overlooking a scenic landscape, the same concept can be applied to augmented reality within an interior setting because every media asset represents a window into another world beyond the realms of physicality, be it musical, visual or textual. [11]

In figure. is a stylized humanoid swarm modulator which is comprised in its minimized form of the user's assets. This augmented reality entity can morph and expand the contents of it's being into preset templates of any shape size or geometric configuration to allow the user to easily select their chosen form of media to access akin to a user opening a folder saved with media on a traditional computer system. However, when the virtual assets expand for interaction in augmented reality environments they occupy 3D space rather than a 2D plane. The first column depicts the user's assets transforming into a diamond geometric pattern with nesting interactive functionality to access varying tiers of media akin to the demonstration of the MR Globals menu described in section 3.1.2. The second column has media assets that have expanded into a rotating pentagonal form that has automation features which can further transform it into a virtual media lattice like freeform plant trellises that occupy the user's interior.

The last column comprises media assets in the wallpaper linear tiling format. The user can choose to occupy portions of the aerial spatial volume, its walls or support structures with their virtual items conformal mapping to environmental features like setting up shelving to store belongings on in the traditional sense.

Figure 3.15 provides a few more examples

Fig. 3.15

Here are a few more examples of potential swarm entity modulators that have different quantities of media composition. Designers are encouraged to design these mobile modulators in accordance with an environment's language of aesthetics to aid visually with environmental integration even if it is only for a given user's personal use. The modulator can take any human, animal, geometric or fantastical shape.

Spatial Scale Modulation

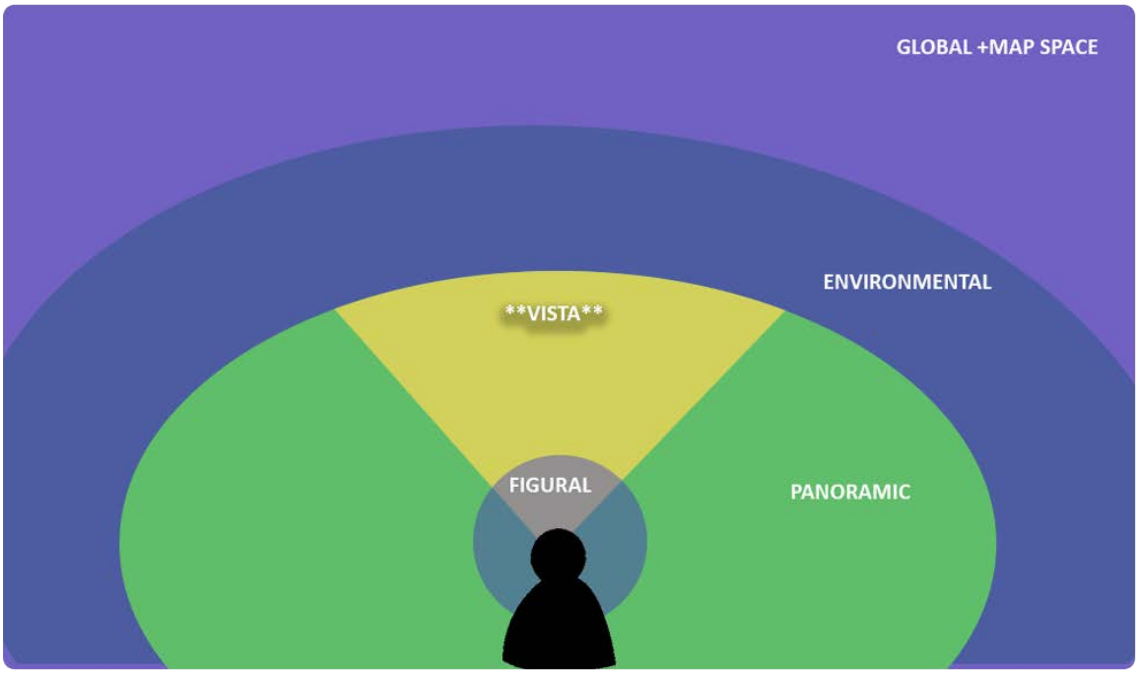


Fig. 3.16 ---[30]

With a solid understanding about the media gradients and the two primary types of modulators fixed and mobile that exist in these hybrid environments, it's time to consider the overriding factor, spatial scale which largely determines the expression of the latter. Spatial scale was previously mentioned in reference to certain media gradients and applicable interactivity functions and it is the aim of this section to provide a basic template to aid in the visualization process of the 3D user interface between these classifications of space. In figure 3.17, are two symbols representative of a default user and media asset inhabiting a mixed reality environment. They will serve as icons to represent the different spatial configurations available for designers to begin to prototype and iterate upon.

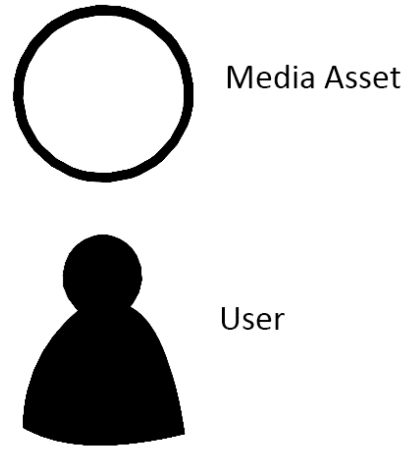


Fig. 3.17

Figural Scale is where the user is placed within an egocentric frame of reference which fosters an immersive and immediate and experience with the virtual/physical interface

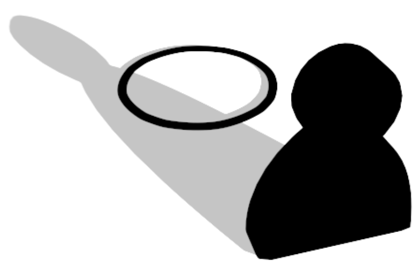


Fig. 3.18

because the individual is within arm's length of the interaction space. Figure 3.18 displays the user with the media asset scaled to be within proportion of the person along with being close in proximity. Figural space is useful when the user needs to partake in small scale tasks that require fine-tuned precision to manipulate for optimal results.

This scale orientation also allows for the representation of global and map scale classifications through world in miniature 3D map projections because each of these scales are too large to be perceived in their native context. It should also be noted that working within figural or any scale to utilize the scale-complexity trade off design modality as a starting basis for the level of detail in the user interface. To recap, representations at a larger scale should be diffuse in the gradient of detail while progressively smaller artifacts should be rendered with greater details. This notion applies in general scenarios and with figural scale, it translates into interface features and media assets containing more complexity where the user is thusly able to make interactions with more precision.

Yet even within figural scale, this scale complexity trade-off is not a homogenous set standard and is subject to modulation based on user settings or the spatial strategies of the specific interior. For example, along a circulation pathway, one of the dominant interaction strategies is figural for accessing mobile interactive menu items yet spatial strategies for this area dictate that media assets should be diffuse because of user's capacity for attentional focus while already being engaged in motion. In this instance the media assets and user interface elements could remain simple and diffuse while the user's first-person ability to interact with these elements could be precise to fall in accordance with tenants of the scale complexity trade-off typifying a heterogenous mixture of scale and interactivity features. [30]

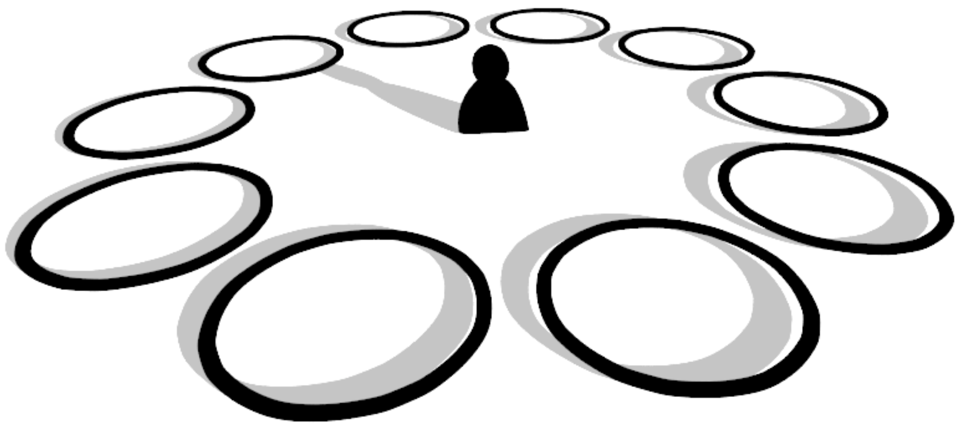


Fig. 3.19

Panoramic scale which encompasses the user's ability to rotate around and perceive the environment from a single point in space is illustrated in figure 3.19. This spatial orientation fosters a sense of immersion by placing the user directly in the middle of the actionable environment, being at one with the interactions in the mediascape through participatory exchange. In terms of media complexity, the general scale complexity trade-off guidelines apply but are subject to modulation as illustrated in our figural scale example with heterogeneous interaction space. The complexity of user interface programs, features and assets will be moderate as a general starting basis. Panoramic space could bring a whole new dimension to tabbed browsing which is currently utilized in most modern web browsers by allow users to distribute their media assets across space. Another reason why this orientation is useful that lie outside the scope of this research project relates to human factors considerations with the individual able to exercise the full range of body motion in interactions with the environmental user interface rather than staying seated all day at a computer workstation which might be a detriment to one's health unless necessitated by a disability. Figure 3.20 demonstrates an illustrative example of vista scale which is a small subsection of panoramic scale and usually utilized in specialized site-specific contexts. This could be an instance where a fixed spatial modulator is applicable and tethered to the zone of expression. Vista scale is useful when a user is relegated or needs to focus on only an area of space. The methodologies of complexity also apply for this orientation. [30]

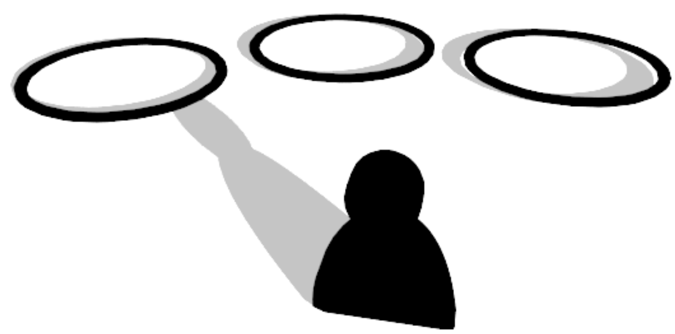


Fig. 3.20

The largest scale aside from global and map scale that can still be perceived via locomotion is environmental scale and this applies within the context of mixed reality interiors as being an indoor building with many sections that requires traversal on foot to experience. The general gradient of media complexity in these spaces is diffuse and these zones serve to acculturate the user with a general impression of where they are orientated in space and the associative functions and features relevant to the locality. 3D spatial interaction functions don't have to be highly specialized or precise in these areas following suit with the spatial strategies and orientations. [30]

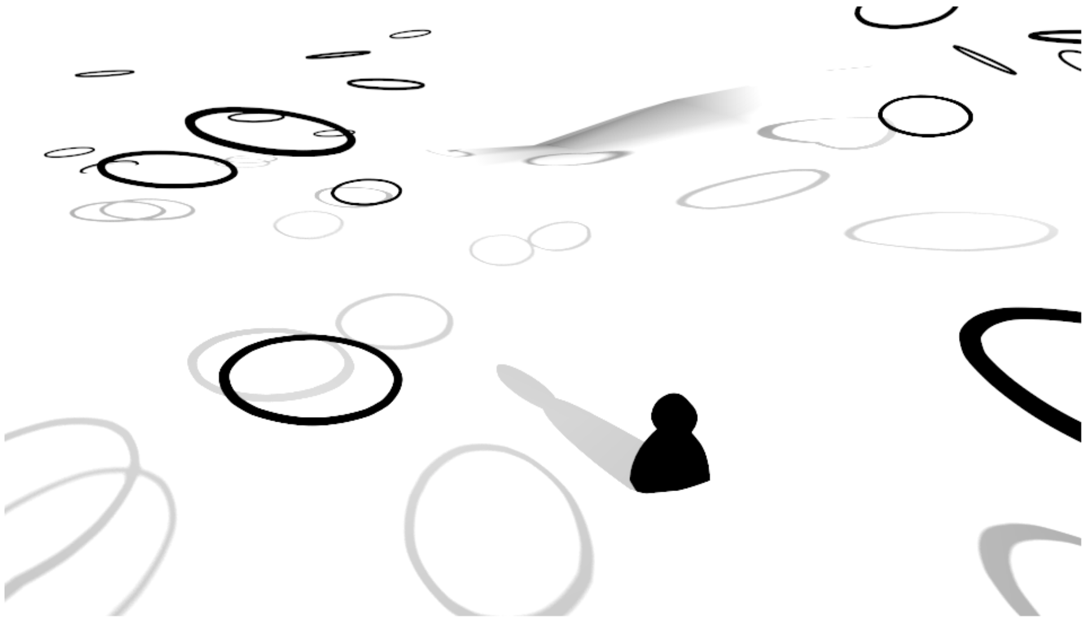


Fig. 3.21

4. IMPLEMENTATION

4.1 Purpose and Thematic Modulators

This section serves to showcase a possible mixed reality 3D UI design concept utilizing consideration of some of the precedents in addition to background and design research methodologies developed in previous chapters. The purpose of this conceptual space is to demonstrate an interior user interface layout catered towards varying interaction types and possibilities within a mixed augmented reality interior setting.

The user can engage in interactions through kinesthetics, socializing, by design or artistic related endeavors along with traditional literature research and study in this environment. Each of these areas comprise the four zones or centers of this interior which functionally work together to support the overall concept of information exchange through various types of interactive possibilities. The layout of this space including the spatial organizational schemes serve as a foundational basis to dictate how user interface elements, functions and interactions vary dependent upon spatial orientation in physical/augmented reality space.

The theme chosen for this space is an abstraction of some elements of the human organism as they are fitting structures to conceptually simulate the discussed interaction and design processes. The entirety of the space when the extended walkways are attached as in Fig 4.1 is shaped like an infinite figure eight with the designated zones/organs of activity nested inside the contours.

The general shape and interactivity of the zone of kinesthetics which serves as an exercise area along with a circulation pathway is an abstraction resembling veins carrying blood in the human circulatory system or similarly nerve pathways.

The zone of study/research is an abstraction of the lung with branching alveoli elements as part of the user interface. The zone of social interactions embodies heart like with the area structured like a cavity of such an organ with the virtual media and people serving as the life blood. And the zone of creation which deals with design and art is an abstracted womb with embryo UI icons emerging from dual light well platforms of interactivity which comprise some of the interface elements that aid the user in giving birth to his or her creations.

A top orthographic view of this interior concept is shown in the below figure with more detail about the features of each zone to be fleshed out later in the following sections.

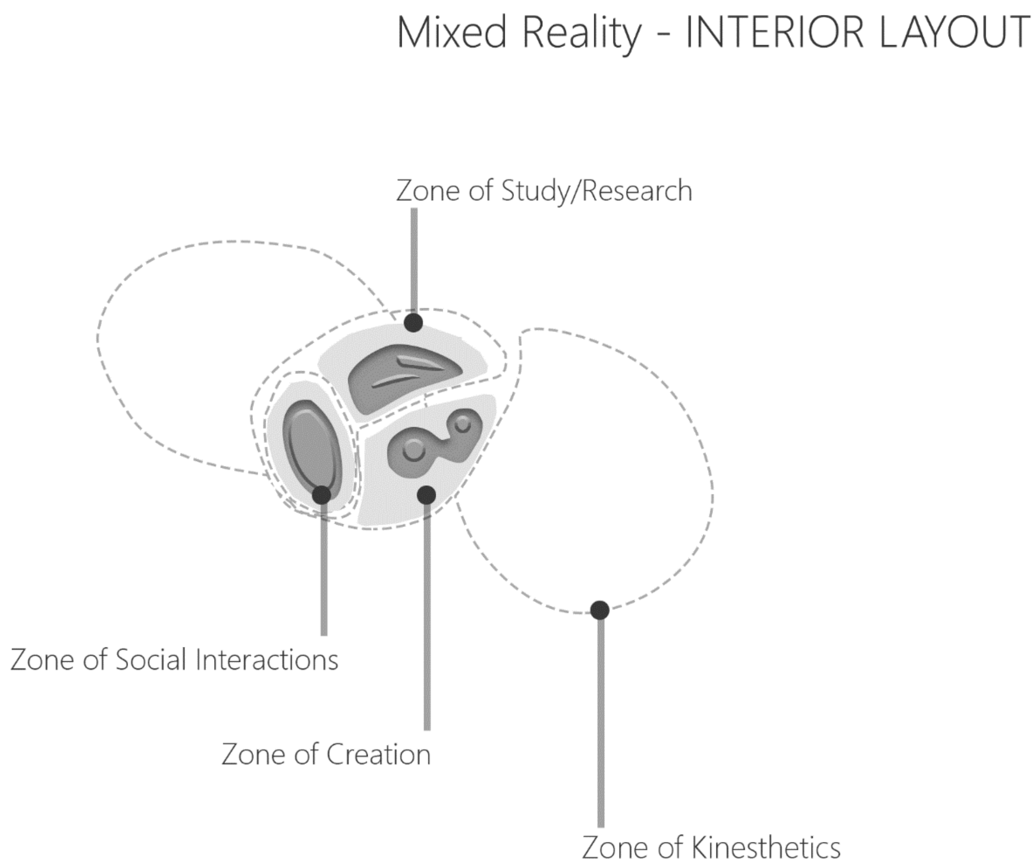


Fig. 4.1

4.2 Mixed Reality Zones

While each of these zones are unique centers of activity for specific interaction types, they share many similar spatial organizational schemes, input/output designations, basic main menu UI functionality along with themes and purposes.

<u>Concept/Purpose</u>

This conceptual space draws thematic inspiration from organic processes related to the human body with each zone's theme working to support this aesthetic goal while varying in purpose. Creating commonality and a sense of similarity between these areas in terms of graphics, shapes and functionality in the interior ensures a fluid easily to navigate user experience. Commonality is established with the UIs in this mixed reality space through utilization of self-similar scaling and nesting rings for the default interface functions for each zone that can be activated by interfacing with a virtual/organic feature site specifically present dependent on the spatial context. The idea is that information media is the life-giving substance and these organic forms modulate the flow or gradient of the virtual assets. These abstract organic elements are simply one of the aesthetic choices for gradient modulators used for this concept, but the design possibilities are limitless, and designers are encouraged to experiment.

General Inputs/Outputs

The outputs of the see-through head worn displays along with environmental haptics and speakers are present in all zones. The user-worn sensor ring and supporting peripherals, the depth cameras placed in various angles of the interior in addition to passive haptic feedback props and sensor embedded homewares are all examples of inputs that each of the zones comes by default with. These standard input and outputs for the mixed reality space enable the user to perceive the augmented reality UI and media assets through the sense of sight, hearing and touch along with being endowed with a basic controller to manipulate virtual objects in space and control the interface. Due to the varying interaction goals of each region, there are also specialized inputs beyond these standard implements to aid towards those ends that will be addressed in each zone section.

Dominant Variable Spatial Strategy – (Fractional Dimension)

Each zone features its own unique composition of organizational schemes which I term as the dominant variable spatial strategy. These schemes will be discussed in the specific zone sections of the chapter. This is defined as the distinguishing elements that ultimately determine the default level of user interface media gradients and functional affordances and constraints. For example, the interactive elements of the zone dedicated towards research and study would differ from the zone for movement and exercise in the controls used to interact with the interface along with the augmented reality programs installed in the area. This variability in the layouts embodies the property of fractal dimensions because the level of complexity can be modulated to a greater or lesser degree dependent upon design goals of the spatial strategies.

Along with possessing these differing elements, the zones of this conceptual space also share commonalities in the following spatial organization schemes:

Space within a Space – Spatial Relationship (Self-Similarity + Recursion)

Each zone shares a similar function that works together to support the purpose of experiential interactions and learning in mixed augmented reality. The centers thematically and function wise are self- similar to this concept and is manifested in the UI templates and the features of the physical space. These templates show self-similar attribute at varying levels of scale via automation or nested loops of functions and interactivity. This translates into the branching scaling ring media UI structures sharing similar navigation and interaction functions throughout each zone of the interior along with having the ability to organize virtual assets via automated templates.

Grid – Spatial Strategy (Scaling)

This traditional interior strategy used most often for rigid cubicle workplace environments is applied here to all zones purely in a virtual sense. This is executed through the environmental cameras 3D mapping the interior and establishing a coordinate system for the movement and placement of objects in mixed reality space. These grids are usually invisible to the user except for select instances during object manipulations. Giving the computer system data about where objects are in space aids in also allowing the user to establish a sense of scaling and contrast in the interior through accurate renderings of occlusion as well as registration of virtual items. This contributes to optimal wayfinding and knowledge acquisition of spatial awareness.

Space linked by a Common Space – Spatial Relationship (Infinity)

Spaces linked by a common space are typically circulation pathways, walk or hallways of any nature. Part of what makes a space connected and easy to navigate while embodying the quality of infinity is by utilizing these types of circulation realms to relate one area to another. All the zones in this conceptual mixed reality interior are spaces linked by a common space as they all require a circulation strategy to reach. On a thematic/purpose level, they are linked to the common space and to each other because of similar design aims.

Network – Circulation Strategy (Infinity)

Network is an interior design circulation strategy that refers to how movements that occur in space are interrelated and connected to one another. For the mixed reality design interface, this definition has been expanded to include the interoperability of UI functions and applications as they transit through varying areas in space. The network provides an outline to dictate the linkages and transpositions of certain elements within all the spaces linked by a common space along with all other organizational schemes. It is the roadmap for infinite connections of neighboring elements within mixed reality space.

It has been outlined how each of the mixed reality building blocks of the fractal dimension, scaling, infinity, recursion, and self-similarity fit within interior spatial schemes and are transposed in the context of digital media principles to construct an interface concept for this hybrid environment experiential learning.

The next four sections will detail more specifics about this design concept culminating in the last section which will provide a general overview of putting all the discussed methodologies and designs together into a working system for further design research endeavors. While the basic physical template for this experimental hybrid space is shown in figure 4.2, the digital components will serve as the walls or partitions and distinguishing elements or lack thereof whilst traversing through the zones.

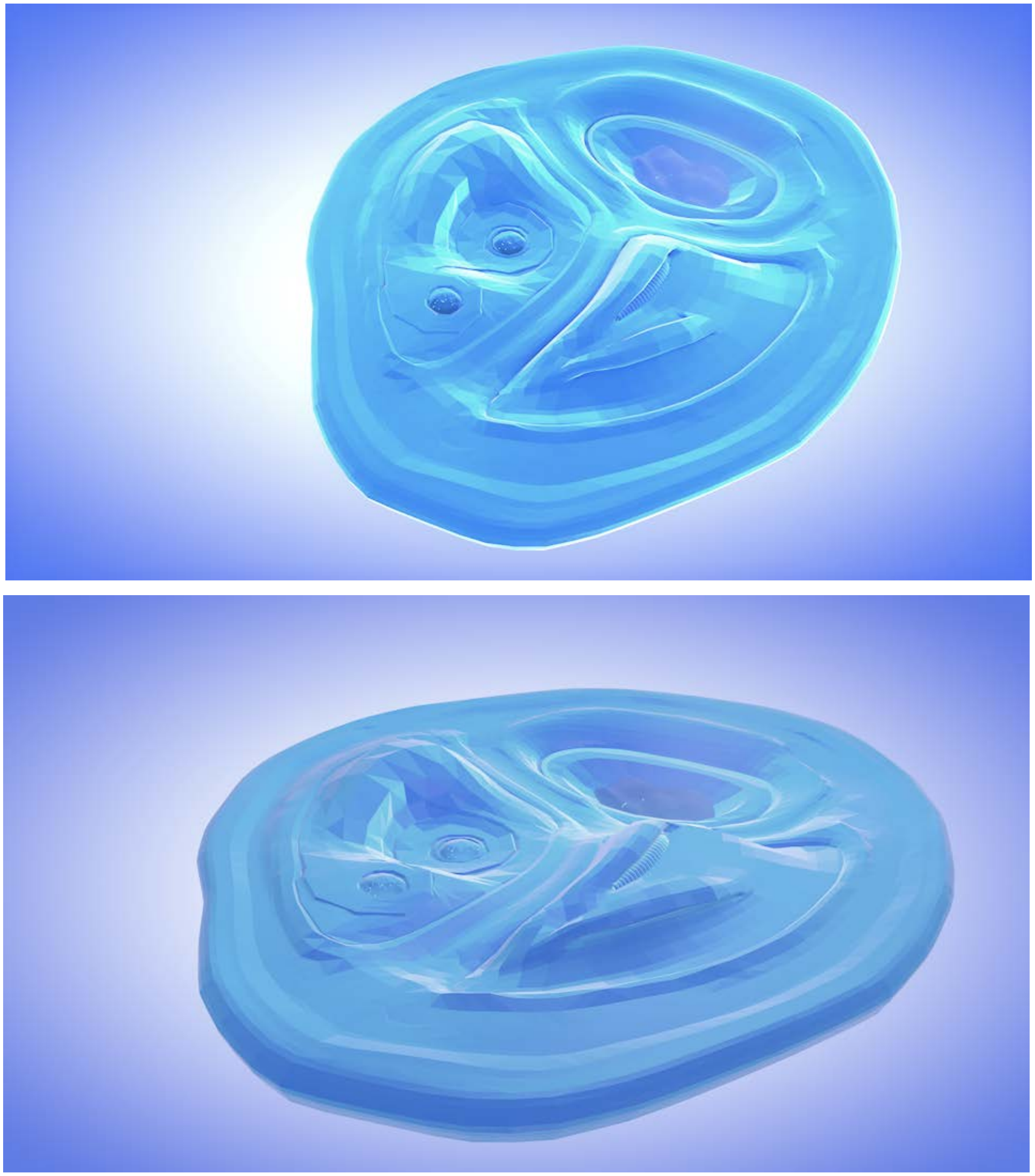


Fig. 4.2

4.2.1 Zone of Creation

Table 4.1

THEMATIC MODULATOR/PURPOSE/GRADIENT	INPUTS/OUTPUTS (Context Specific)	SPATIAL ORGANIZATIONAL SCHEMES
PURPOSE: **Design/Artistic creation through varying modalities** SCALE MODULATION: **Panoramic + Figural + Vista** THEMATIC MODULATOR: **Abstraction of womb space, embryonic growth, seeds of inspiration, order out of primal chaos** ****(Fixed Spatial Modulator by default because of zone specificity but also capable of housing Swarm Entity Modulators)* GRADIENT: **Intermediate**	INPUTS: • Pen Tool • Passive Haptic Feedback Props/Homewares • Virtual Keyboard • Depth/RGB Camera Sensor • User worn sensor ring + peripherals OUTPUTS: • See Through HWD • Environmental Haptics • Speakers	• Network – CS • Space within a Space – SR • Space linked by a common space – SR • Clustered Strategy – SS • Grid - SS 

Each new era ushers in changes in the way artists and designers create works that aid in helping to grow, advance and conceptualize the world around us. We are living in the digital age yet nested within the natural world which is all around us and most importantly the organic forms that comprise a part of who we are. Functions of a computer system mirror natural properties of an organic ecosystem with the converse also being true and the spatial layout of this zone as well as the interactive functions embody this relationship which integrates purposefully with the other centers along with the whole interior.

It is the aim of this realm to shift the user's perceptual state into receptivity for the conception and execution of design works relevant to their chosen discipline through placing the user at the helm of mixed reality womb space. Applications for drawing and painting along with 3D modeling, sculpting and computer graphics are present. Typically, during the creation process, a designer needs to collect reference imagery or varying types of multimedia as a design research precursor to inform their projects. One of unique affordances of this augmented reality medium is that this type of endeavor is no longer relegated to a 2D computer screen because assets can be positioned all around the user in mixed reality space lending to a more streamlined creation process.

Keeping in alignment with the organic theme of the interior, the fixed modulating user interface elements in this abstracted womb space include the icon seed particles nested within the fluidic substance of the zone's dual lightwells of inspiration. From these access points, the user can initially activate the UI, functions and applications of the zone. They also act as platforms for the user to engage in multimedia creative brainstorming as well as hubs for artistic creation.

The media gradient here ranges from intermediate to complex because the act of creation is a chaotic process and it is the working endeavor of the designer to bring order out of this media chaos by piecing together seemingly dissimilar elements to give birth in this mixed reality womb space to new artistic and design works and concepts.

The zone of creation features the standard input setup of devices already proscribed in the first section with the addition of a physical pen tool device to allow users to make more fine-tuned movements during the process of creation. Additionally, this realm is capable of housing moveable passive haptic feedback wares in the form of seeds as seating or decorative implements that can control elements of the 3D user interface with hand or touch gestures.

Spatial organizational schemes for this setting follow the strategies proscribed for the interior as well except for the additional clustered strategy which was also utilized in the zone of social interactions. The clustered strategy is relevant in this area of the interior because this format caters towards the artistic process of discovery by affording the user with the ability to place works, imagery or concepts around the space in a loosely scattered fashion to draw creative inspiration from the unstructured meandering.

4.2.1.1 UI Interaction Features

0. Mixed Reality Globals – Component 

Mixed Reality globals is the default menu set embedded within every zone of this interior. It allows the user to perform operations essential to the function and maintenance of mixed reality environments such as saving or recycling media assets, sharing applications, user preferences and setting, templates, linking and other tasks in this vein.

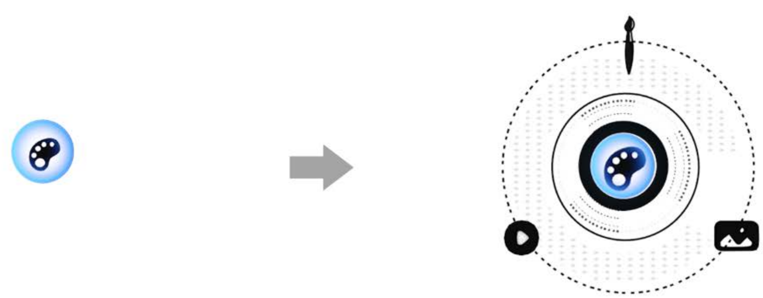


Fig. 4.3

1.

The palate icon houses the default functions for the creation zone which include a applications for design, recording, playback, imagery collection and spatial dispersion.

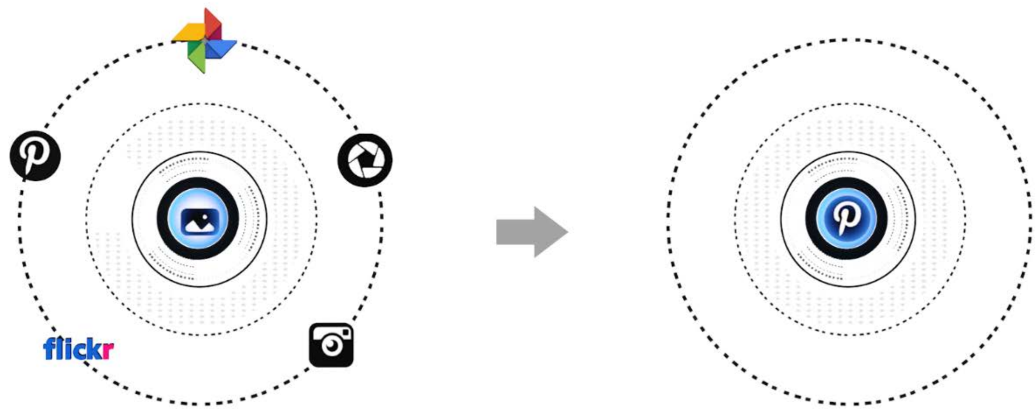


Fig. 4.4

2.

The image icon is selected and then the previous options are minimized and nested with a third ring expanding to revel image discovery sites and applications, Pinterest is selected and then the application is selected with user exiting out of the main interfaces, yet the icon is still accessible in the zone if other options need to be selected.

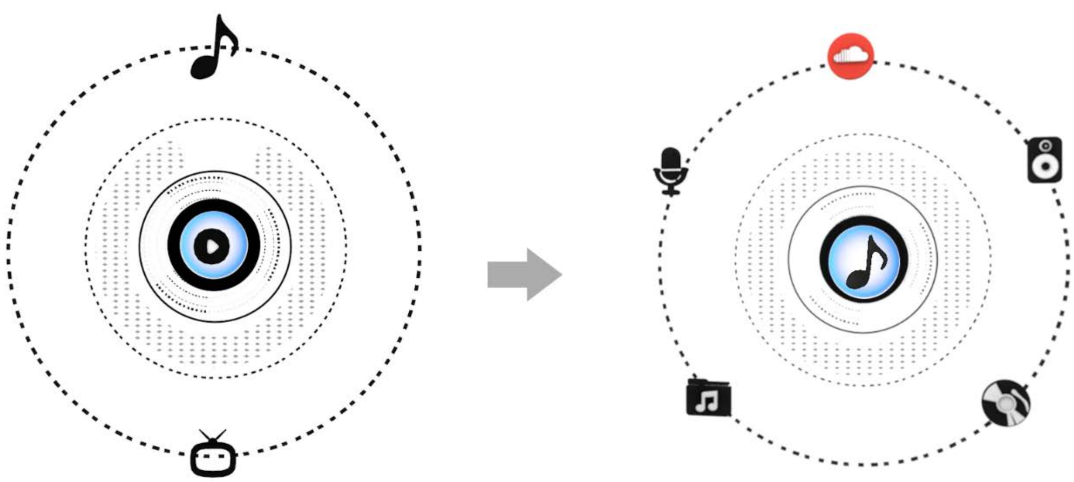


Fig. 4.5

3.

In this instance, the play option is selected and for this zone the media gradient has determined that only music and video playback are options. Music is selected, and another ring expands to reveal more features including, playback, SoundCloud, playlists, a DJ app and recording capabilities.

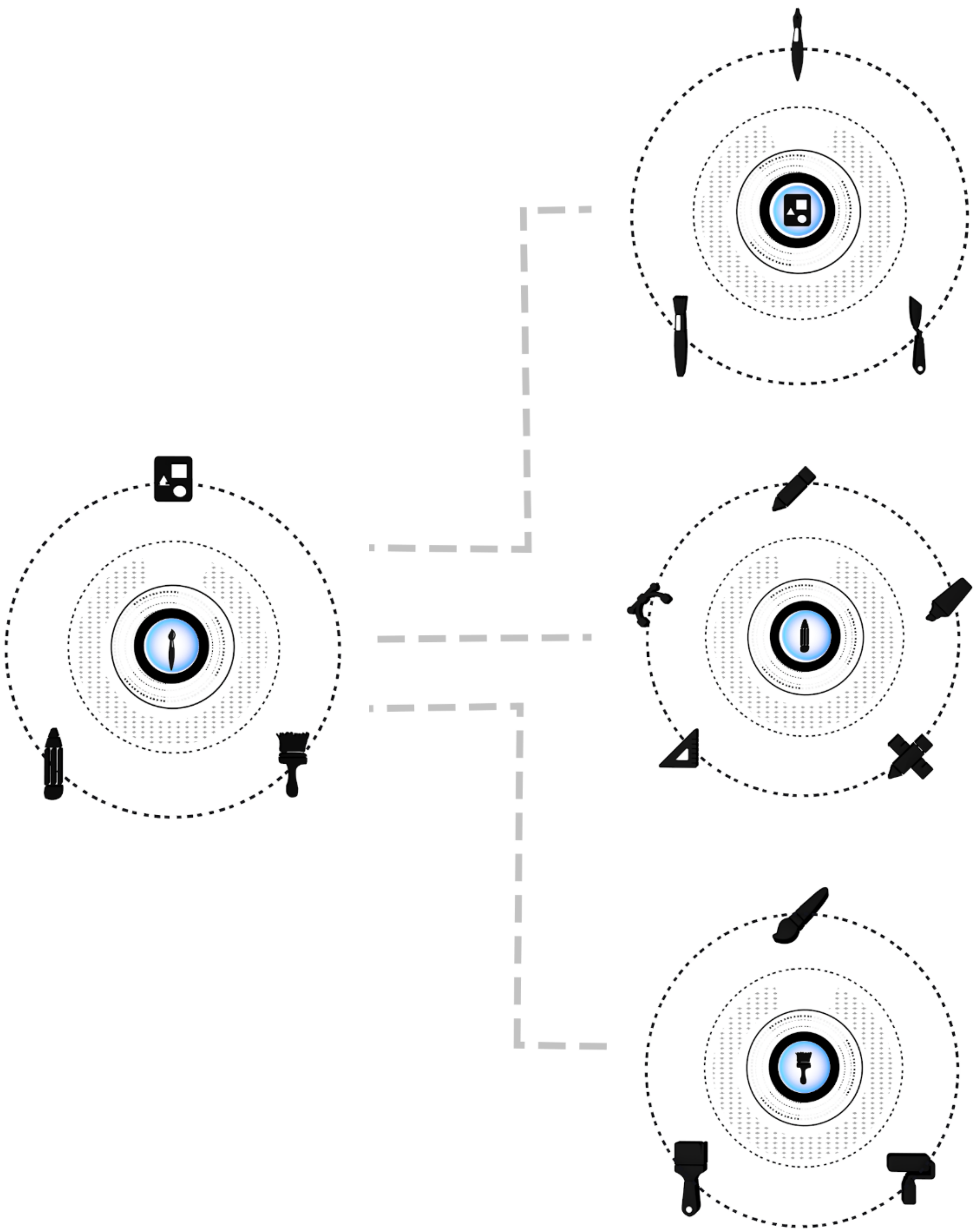


Fig. 4.6

4.

The augmented reality art/design tools are demonstrated in the above figure which are inclusive of virtual painting, drawing in addition to 3D modeling and sculpture

4.2.1.2 Integration

Fig. 4.7

This shows a top down orthographic angle of the creation zone along with an eye level perspective of a user inhabiting the realms sans the inhabiting media forms with the exception of the augmented reality water/lightwell hubs. This area is set up to allow the individual to meander around as well as between the two focal points hubs while engaged in their design endeavors to encourage a sense of discovery in play,

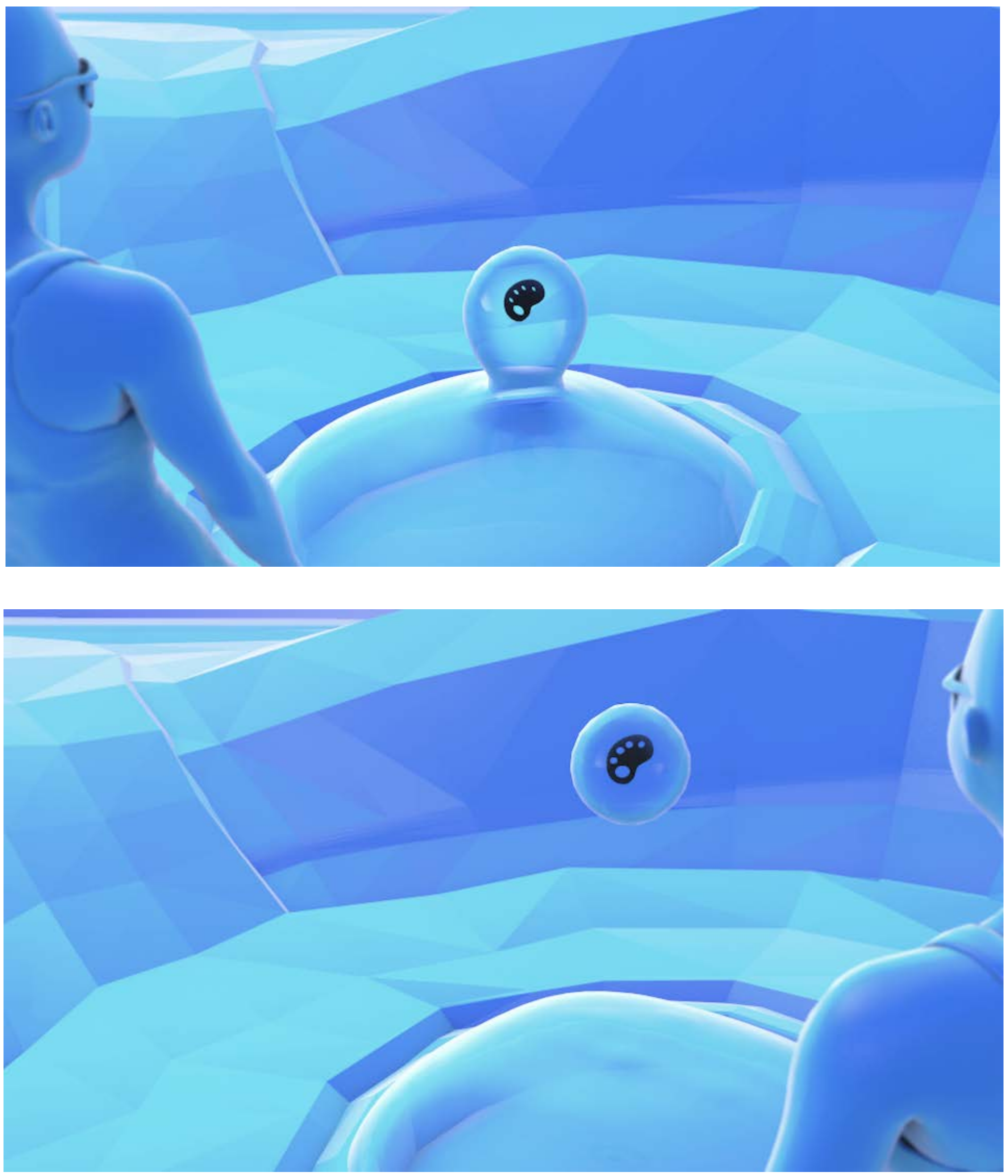


Fig. 4.8

contemplation and exploration. The hubs or the circular areas of this womb creation zone house the augmented reality wells which contain the user's customized projects or assets in minimized form or icons and functions relevant to the area. In this instance, the user selects the creation icon symbolized by the palate and the water molecule seedling cell emerges from the well.

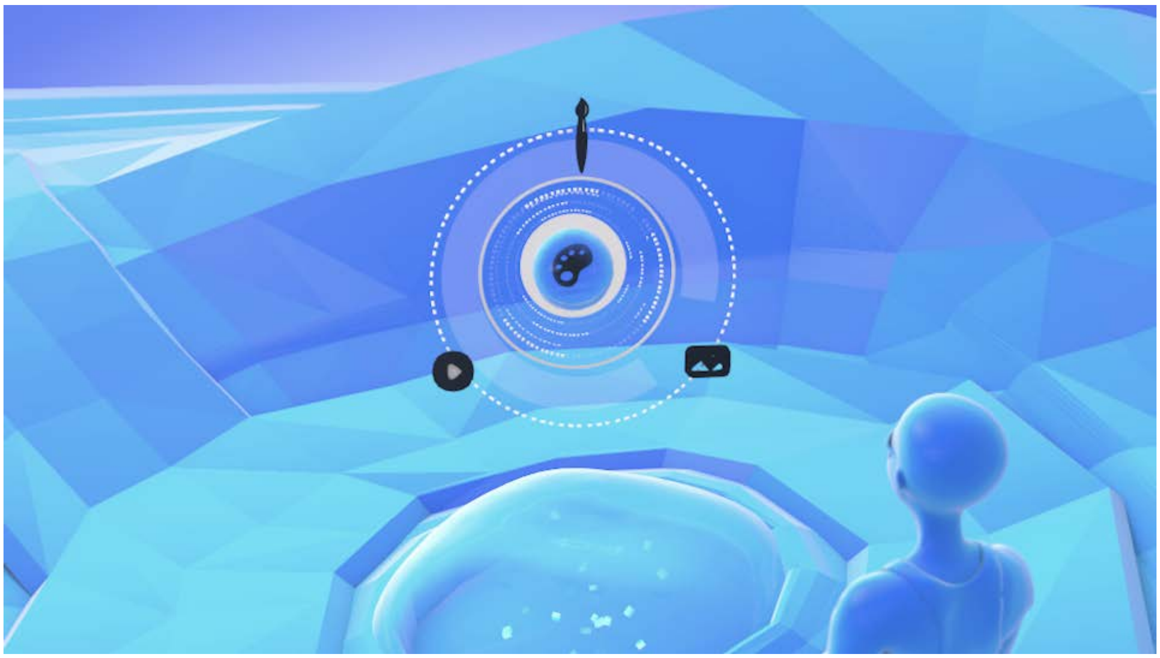


Fig. 4.9

It subsequently separates from the surface and then expands its rings to display the primary function set of this realm which includes, design tools, musical/video playback functions as well as imagery project storage along with perusal.

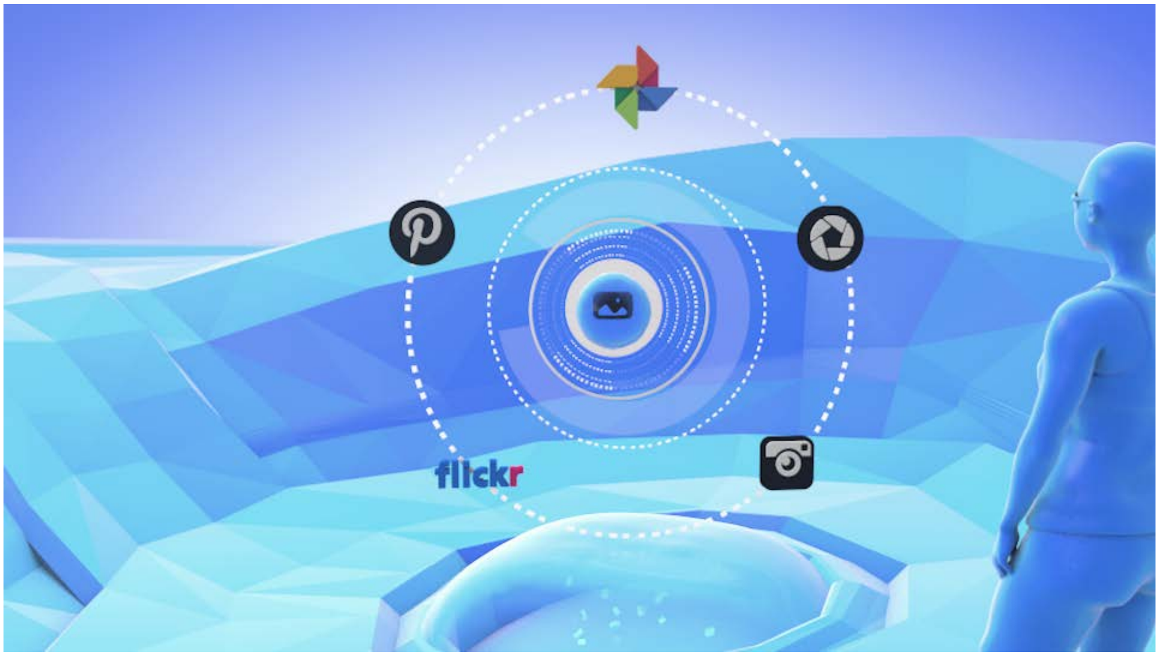


Fig. 4.10

The rings expand once more to show commonly utilized apps and display types for imagery in interactive applications. The Pinterest app is selected and then the program is executed in the zone. Imagery fills the volumes of spaces initially providing the user with a variety of options on how they can search for, experience and display this media in their environment. In fig. 4.10 the user walks up the incline to the other AR water well and starts drawing out imagery in which the system starts arranging the assets into a kaleidoscope and starts to spin the media out into space following a path animation along the walkway of creation space.

The user walks back down to their primary starting point and then adjusts parameters to have the imagery map to the contours of the space which is an automated feature of zone media asset conformal mapping.

These illustrations provide a conceptual approach to reimagining how commonly used web applications can be transposed into a spatial mixed reality setting and take advantage of some of the affordances of the space to allow users the creative freedom to peruse arrange and manipulated their saved and pined imagery, lists and boards in and engaging and fun format. The user started off in figural and vista spatial scale orientations to select and manipulate the initial user interface and then the Pinterest application transitioned the user into panoramic space with it's imagery flood only to bring the user back to vista mode when focusing on certain image assets.

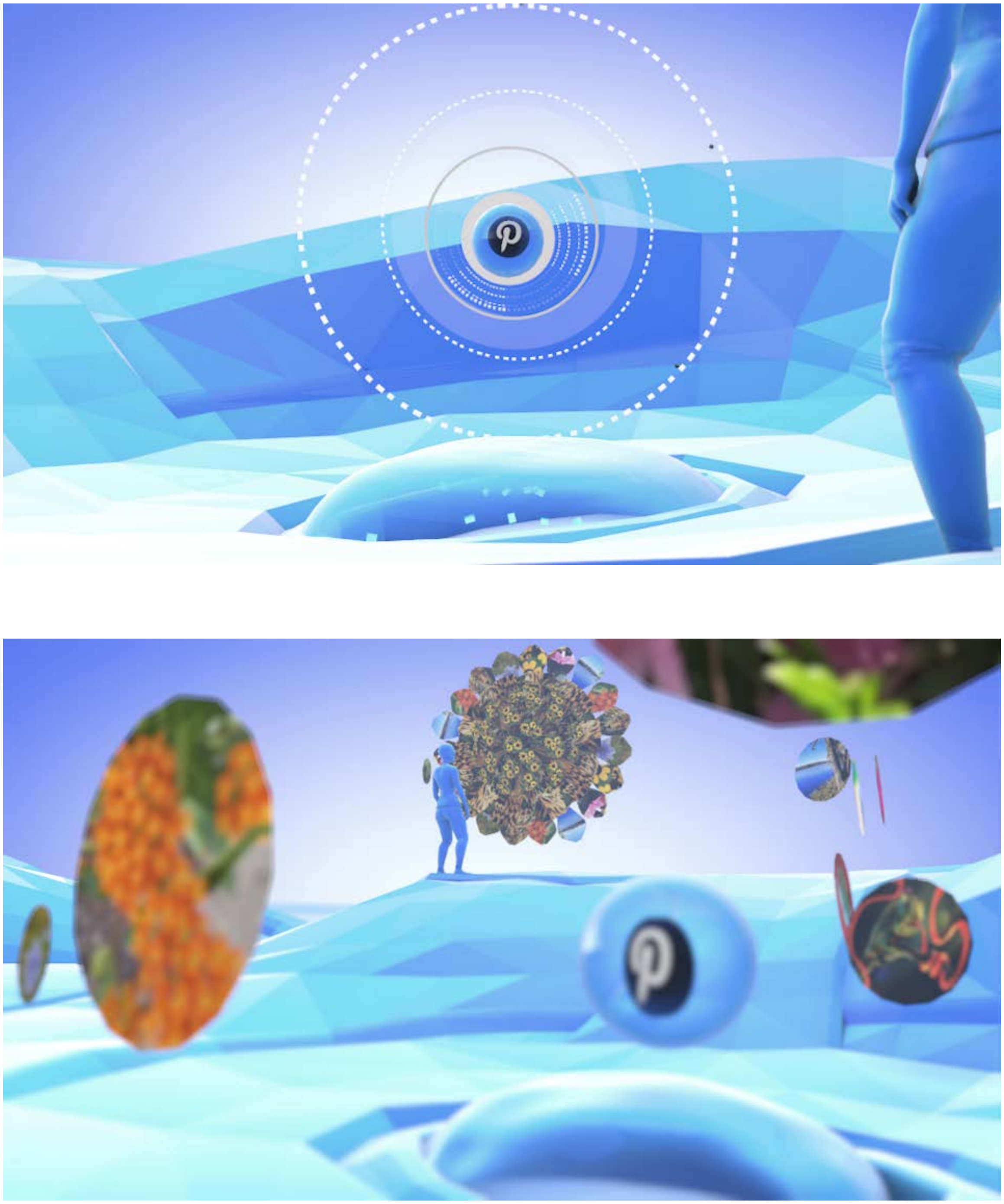


Fig. 4.11

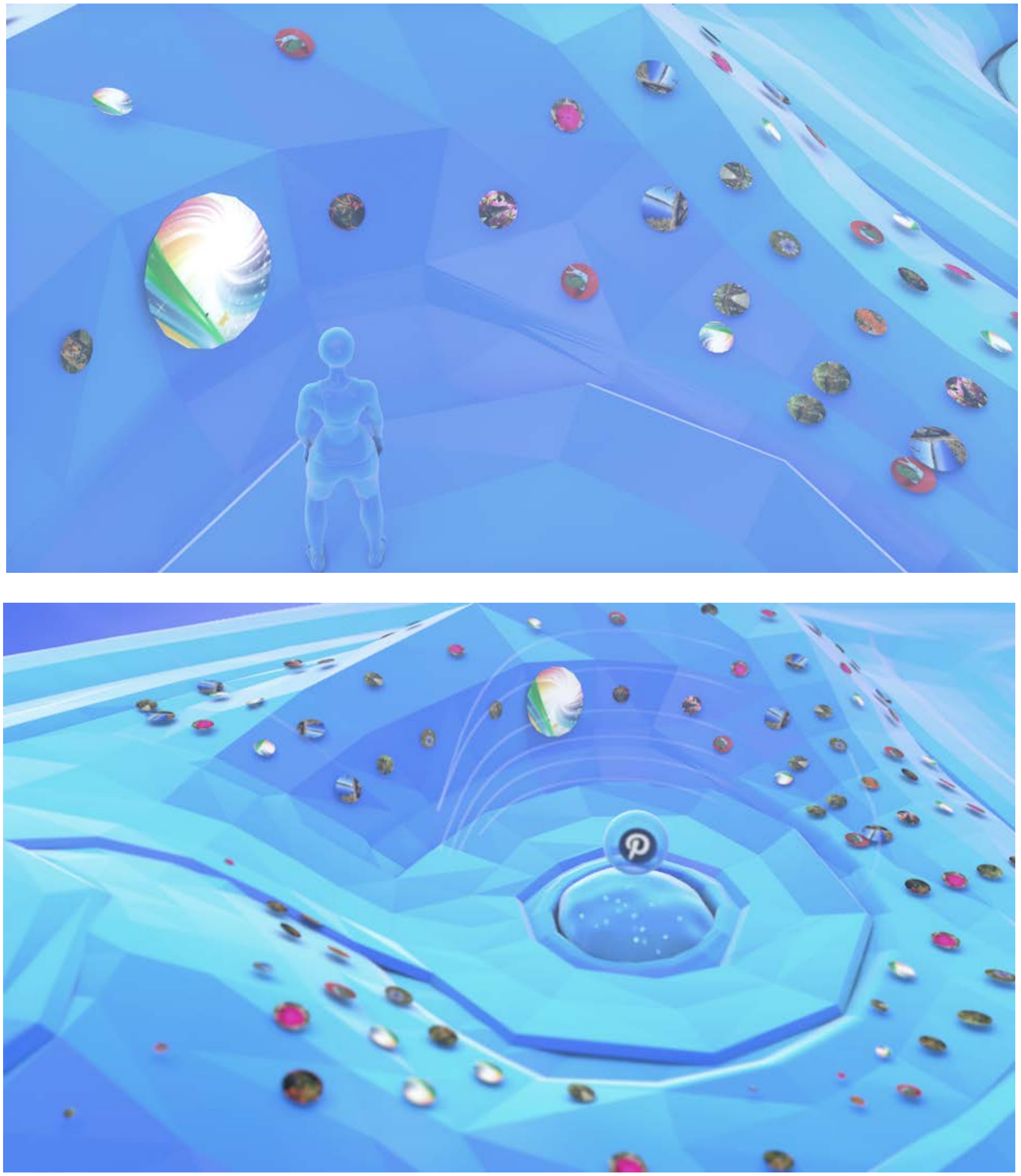
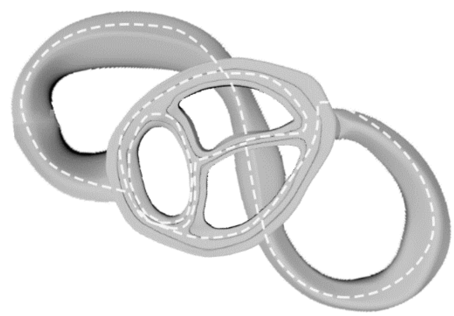


Fig. 4.12

4.2.2 Zone of Kinesthetics

Table 4.2

THEMATIC MODULATOR/PURPOSE/GRADIENT	INPUTS/OUTPUTS (Context Specific)	SPATIAL ORGANIZATIONAL SCHEMES
PURPOSE: **Traveling pathways through space, movement, exercise, learning though motion** SCALE MODULATION: **Panoramic + Vista + Environmental + Figural** (includes global and map scales as these would not be visible under normal conditions) THEMATIC MODULATOR: **Circulatory System or nerve synapses abstraction, the fire of action, activity and movement** ****(Fixed Spatial Modulator by default because of zone specificity but also capable of housing Swarm Entity Modulators)* GRADIENT: **Diffuse + Intermediate**	INPUTS: • Passive Haptic Feedback Props/Homewares • Virtual Keyboard • User worn sensor ring + peripherals OUTPUTS: • See Through HWD • Environmental Haptics • Speakers	• Network – CS • Space within a Space – SR • Space linked by a common space – SR • Grid – SS 

The Zone of Kinesthetics is what is known as a circulation pathway in the interior design paradigm as it aids inhabitants of an interior to travel from one area of the space or room to another. It employs all the default spatial organization schemes discussed in the first section of this chapter, however, special emphasis should be placed here to not that one of its core physical functions is that is the common space that links all spaces instead of the converse. This zone features simply the default input/output modalities within this transit realm and the gradient density is set to diffuse given consideration of the cognitive affordances of the user already engaged in the traveling activity.

Given context of this zone existing in a mixed reality setting, it's primary function of travel can be transformed to include other intentional enjoyable and purposely useful interactive features. This area can also be used for immersive exercise programs where one can learn and train through motion while also being a medium for quick messages or status updates for the weather or media contacts. This zone it outfitted with the standard stationary modulator that is fixed to the zone's spatial orientation which the exception of it aesthetics in graphics and interaction being that of veins

This zone is also a prime candidate for a user's swarm entity modulator to showcase its abilities. Often when traveling from room to room within the interior of a larger building, some of the spaces might not be optimized for mixed reality and have the user's customized attributes already set. This is when the mobile gradient modulator of the swarm entity housing the user's personal assets becomes useful in maintaining customized settings amongst variable environmental conditions.

4.2.2.1 UI Interaction Features

0. Mixed Reality Globals – Component 

Mixed Reality globals is the default menu set embedded within every zone of this interior. It allows the user to perform operations essential to the function and maintenance of mixed reality environments such as saving or recycling media assets, sharing applications, user preferences and setting, templates, linking and other tasks in this vein.

Fig. 4.13

1.

The user selects the running man figure which houses the default functions for this zone which include, exercise fitness programs, heart-rate monitors, time keeping along with navigation and wayfinding functions in addition to agenda, weather and other personalized user features.

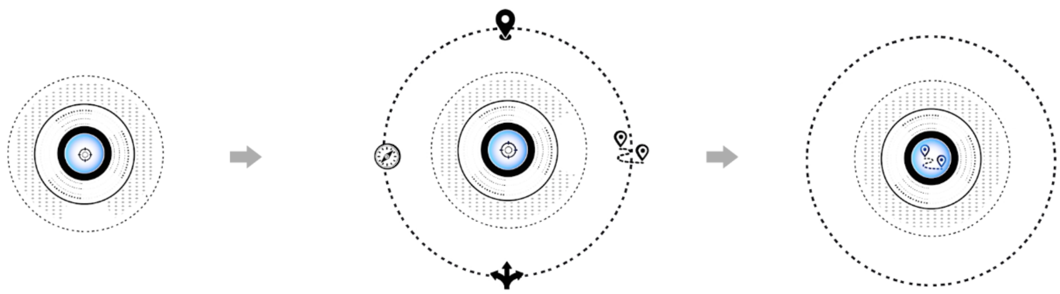


Fig. 4.14

2.

The way finding option is selected and the rings expand to reveal more navigation options. A Realtime AR trail overlay navigation application is chosen which activates the program and exits the user out of the primary interface.

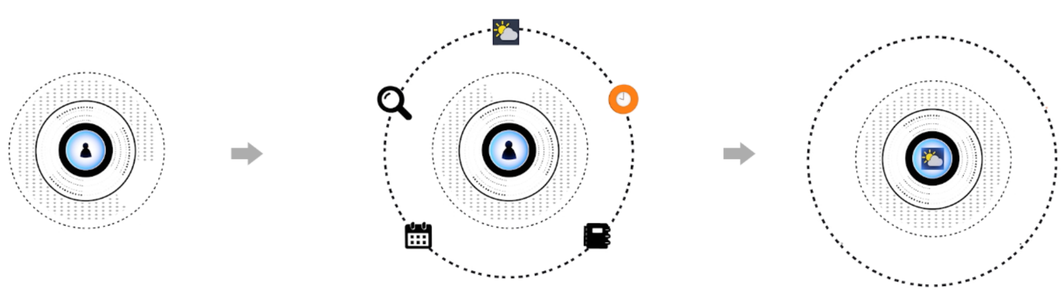


Fig. 4.15

3.

User personalized icon is chosen which expands a ring to reveal certain applications the user has customized for inclusion in this list which include the weather, an agenda, a clock, search functions and a calendar.

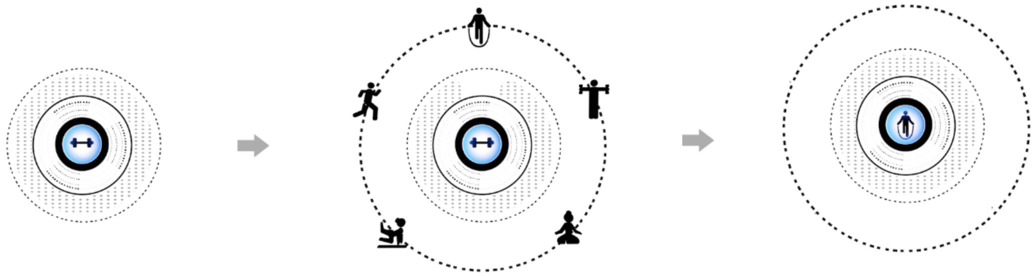


Fig. 4.16

4.

The barbell function is selected here which is representative of exercise functions that a user could engage in which operating inside of this zone suitable for movement and activity. The tertiary ring expands to reveal a variety of programs inclusive of many types of calisthenics, stretching and running. The jump rope option is selected which initiates an augmented reality program in which a user must navigate and jump through a series of virtual jump ropes as a means for personal fitness.

4.2.2.2 Integration

Fig. 4.17

This is the bare bones of part of the circulation zone area without any inhabiting media forms. It's default function is to allow the user to transit from one area in space to another.

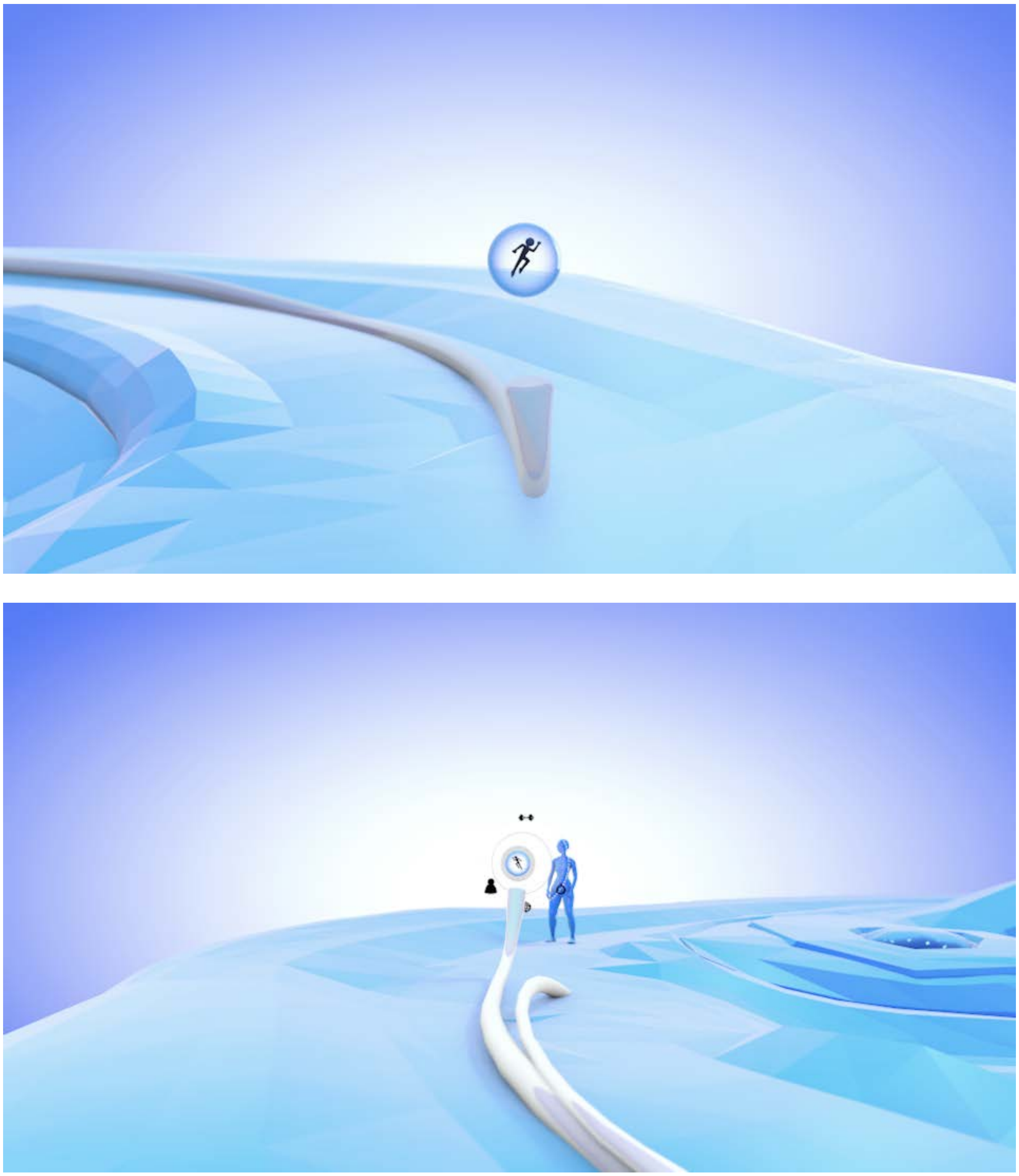


Fig. 4.18

The visual metaphor utilized for this zone was one of veins, or even nerve passageways because of the rapidity of movement being likened to the user that is in motion as well. Above we see an augmented reality overlay of veins projected on the surface of the walkway emanating an icon nerve pulse of an icon the user can interact with. The user then selects the running man icon and the four addition functions are display for perusal which include the barbell which contains exercise programs. The locator for wayfinding and directions, the stopwatch for clock, timing, heart rate along with other user vital statistics along with user icon for customized apps for everyday quick access.

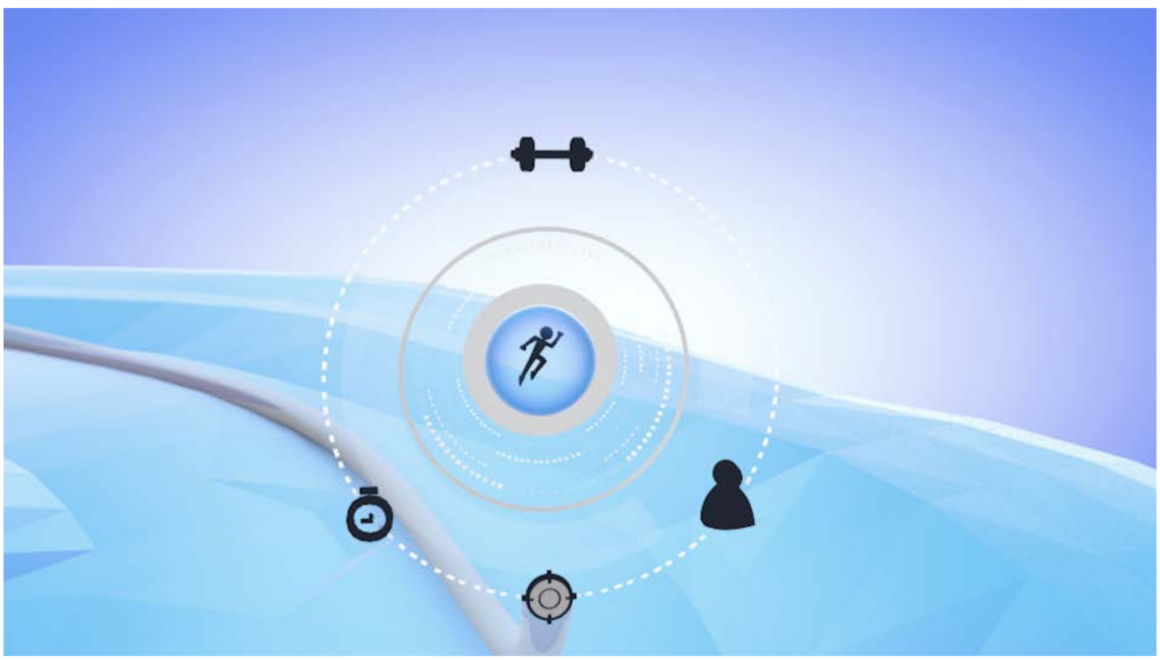


Fig. 4.19

The user icon is chosen and then it presents additional functions including, a calendar, an agenda, a system search field, a clock as well as the weather.

Fig. 4.20

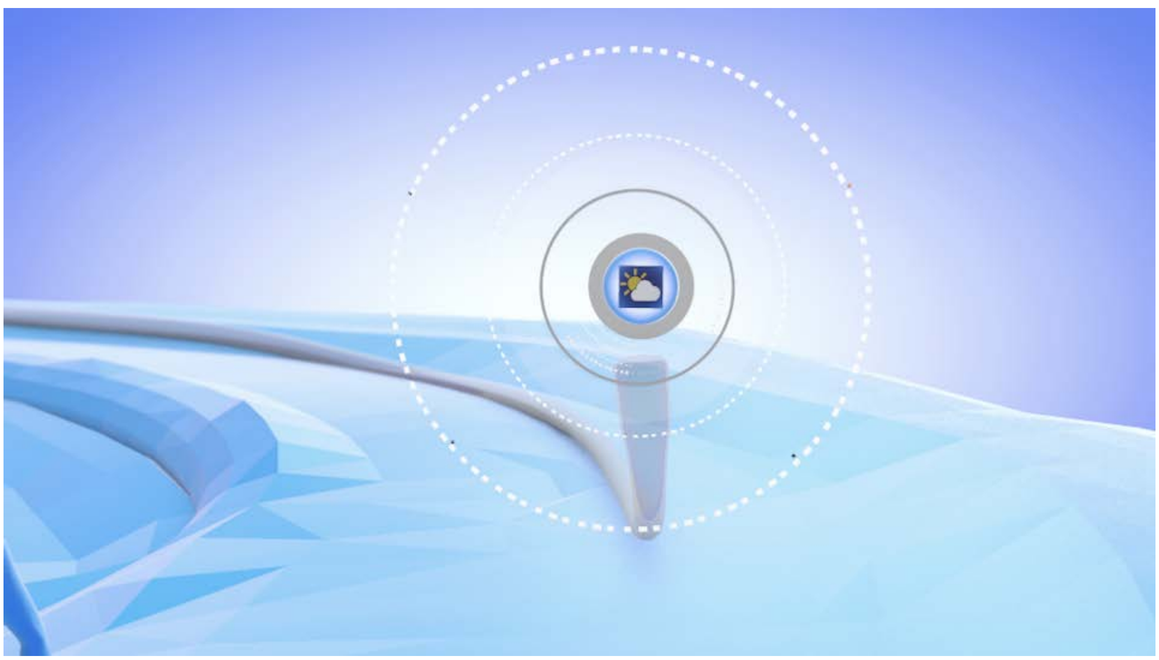


Fig. 4.21

The weather app is chosen and then the program distributes the forecast throughout the user's space which can remain maximized for minimized at their behest. Something important to not here is that this element can be locked to be a semi-permanent fixture in the user's space if desired. Think of it like widgets being dragged out onto a traditional user's desktop or smart device home screen only this is within the volumes of space and only present when in the circulation zone. This also ties into the notion of media gradients according to zone specificity. User's that are typically on the go will be traveling outside of this interior space and will invariably will be met with the climate. Rather than clutter up the user's visual landscape by showing the weather everywhere, it is shown in the circulation zone due to relevance of predictable future activities.

Fig. 4.22

In the next array of images, we see featured an augmented reality swarm entity or mobile moderator as discussed in the previous section. This consists of a humanoid, animal or abstract entity comprised of an aggregate of the user's programs or media access that can also function as a navigational agent during certain wayfinding tasks. Here it walks along the pathway with the yellow trails it leaves behind leading the user to different points in space. Although this is a simplistic demonstrated, the opportunities for usage of vast. For example, the swarm entity could be synched with the user's agenda for the day inside the interior and visit and draw out energy light trail pathways interconnecting all destination points with message dialogue windows as a way of the user keeping track of their appointments and tasks.

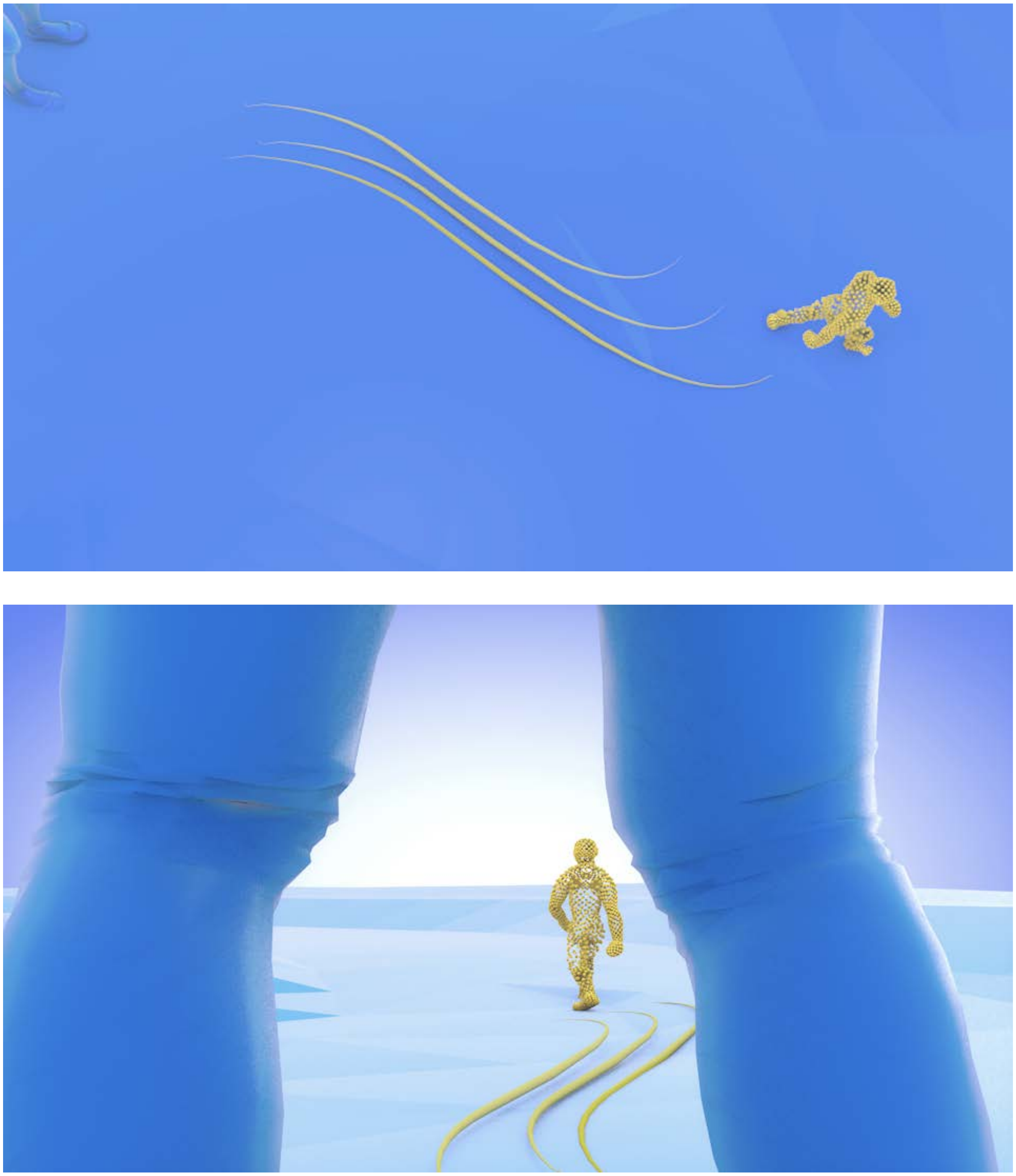


Fig. 4.23

Fig. 4.24

Here is another illustration of the mobile media moderator walking along the pathway and then transforming into it's amorphous swarm state before morphing into the user's personalized lists and scheduling interface.

Fig. 4.25

The entity now takes the shape of the user's schedule along with a digital girdle being attached to the individual's mid-section to allow for ease of access of virtual manipulation tools and widgets. The one featured here being a virtual keyboard to allow the user to type in messages for their agenda's calendar and to do list. The girdle and spin around and multiple other tools can be added to removed from it docking platform.

And, in the last image, the swarm entity has shapeshifted into an audio playback widget. Since we are dealing with Mixed reality, once this widget is activated, a world miniature map of the entire space is figural maximized to the user as well to allow the individual to specify which zones audio will be present in the ambient.

Fig. 4.26

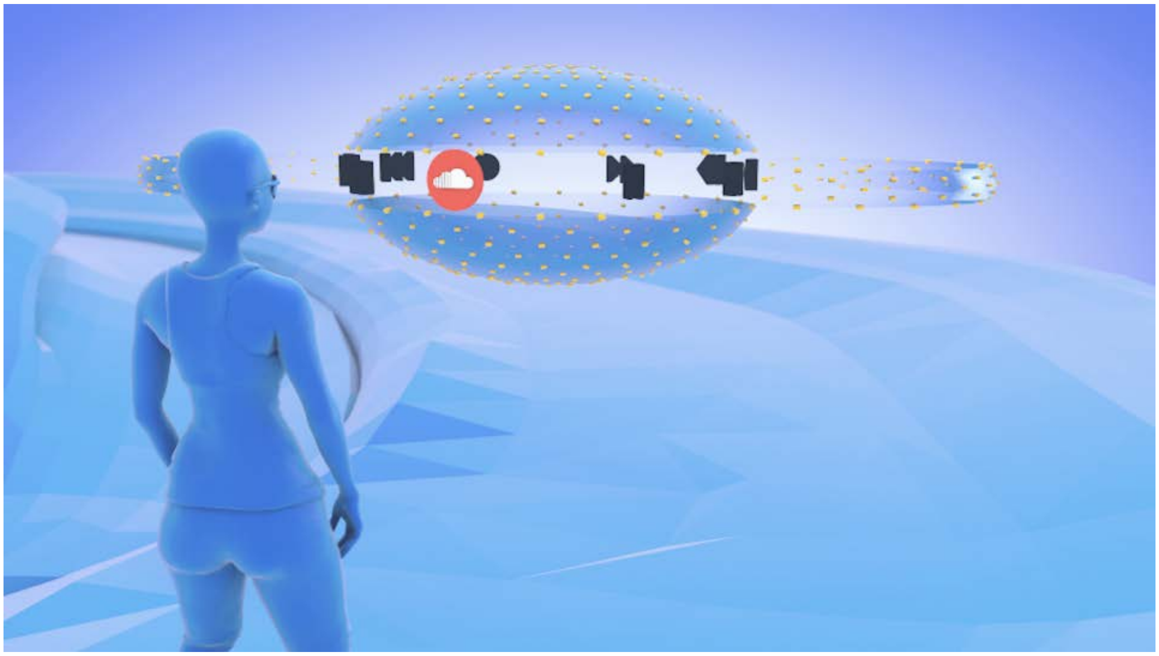
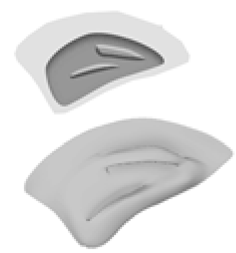


Fig. 4.27

4.2.3 Zone Study/Research

Table 4.3

THEMATIC MODULATOR/PURPOSE/GRADIENT	INPUTS/OUTPUTS (Context Specific)	SPATIAL ORGANIZATIONAL SCHEMES
PURPOSE: **Information gathering, study and research** SCALE MODULATION: **Panoramic + Figural + Vista** THEMATIC MODULATOR: **Lung alveoli abstraction, branches of knowledge, linkages and connections between information streams** ****(Fixed Spatial Modulator by default because of zone specificity but also capable of housing Swarm Entity Modulators)* GRADIENT: **Concentrated**	INPUTS: • Passive Haptic Feedback Props/Homewares • Virtual or physical Keyboard • Depth/RGB Camera Sensor • User worn sensor ring + peripherals • Handheld + traditional mouse OUTPUTS: • See Through HWD • Environmental Haptics • Speakers	• Space within a Space – SR • Space linked by a common Space – SR • Centralized – SS • Grid – SS 

This zone comprises a simulated conceptual prototype of all the ingredients necessary to construct a mixed reality area in space dedicated for study, research, or educational related endeavors. The media gradient is concentrated with menus and options in this zone with the greatest amount of options and variability along with the greatest detail in terms of controlling user input manipulations isomorphic and non-isomorphic. This is necessary because this zone might be utilized for a variety of research or educational purposes and there might be augmented reality applications that call for fine granularities of movement and precision. The input modes of this area would afford for this amount of control whereas areas such as the circulation zone would not utilize these functions because of the media gradient and purpose being diffuse.

The applications as well as the design of this zone are geared towards education in a variety of immersive formats. These include spaces left intentionally open to accommodate the user walking around and interaction with volumetric video capture in addition to 3D assets along with extruded forms in space to allow for the user to experience haptics in either a passive or active format. For example, as the user enters the space, there is a long-extruded strip that blends within the space that users could sit on, but it also doubles as a surface where users could have their augmented reality keyboard projected onto if they became fatigued with the mid-air gestures and inputs after prolonged usage. This is a conceptual step in the direction of weighing design considerations with human factors concerns though detailed investigations into this subject is beyond the scope of this research endeavor. However, it is still useful to begin consideration when creating these archetypes and concepts.

The shape of the overall space resembles that of a lung to tap into the thematic aim of the breath of knowledge, insights and inspiration. Also, with it being the abstracted shape of the lung, the fixed gradient modulators are tree like structures populating the zone which resemble the alveoli cluster air sacs of the lung. Each sac has the potential to house an icon, file, or function that the user can have easy access to without navigating through a menu system. The alveoli also have functions of their own to indicate status to the user such as a status message of some sort among other notices. The user can have as little of as many of these alveoli icon trees as desired in their space.

This zone encompasses Panoramic, figural as well as vista scale modulation for it's 3D user interface elements by default with map scale becoming relevant if a user were to examine a layout map of some type of larger or global setting in vistal or figural scale. Panoramic is the most immersive user interface format in this zone and it is relegate to the user's pursuits of physical walking around and interaction with 3D holographic items. Figural scale in present in the UI with the user engaged in more acute tasks that require precision such as writing, typing or utilizing some type of medical or scientific simulation application. Vistal scale, a small subsection f the panoramic encompassed some of the affordances of both the figural and panoramic scale modalities to lesser extent.

4.2.3.1 UI Interaction Features

0. Mixed Reality Globals- Default

Mixed Reality globals is the default menu set embedded within every zone of this interior. It allows the user to perform operations essential to the function and maintenance of mixed reality environments such as saving or recycling media assets, sharing applications, user preferences and setting, templates, linking and other tasks in this vein.

Fig. 4.28

1.

User selects default icon for functions of the study/research zone and then a secondary ring expands to show more options which include, applications for word processing, eBooks, email, imagery and pictures, scientific simulation applications as well as web browsers.

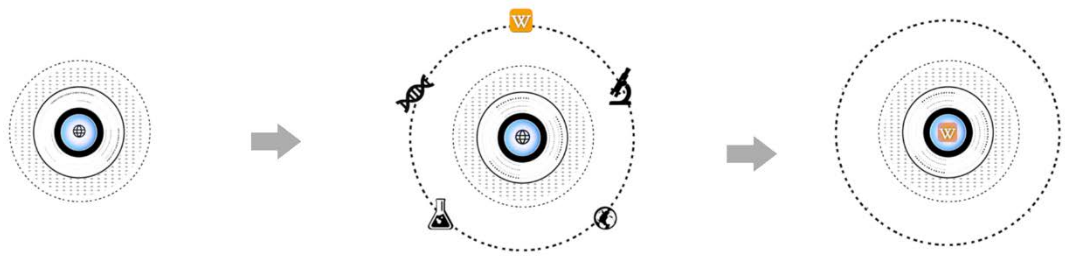


Fig. 4.29

2.

The applications/web icon is chosen and a tertiatry ring expands to reveal more programs and options.   The user selections the wikipedia option which initiates the launch of the program in the user's environment.

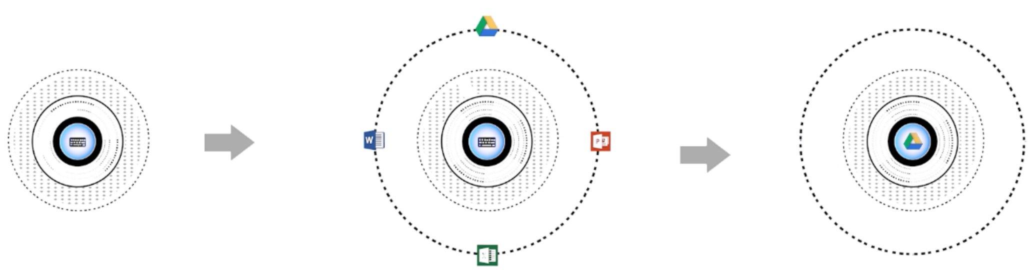


Fig. 4.30

3.

The word processing option is selected in this instance and thing more rings expand to demonstrate options in which google drive is chosen which runs the application.

4.2.3.2 Integration

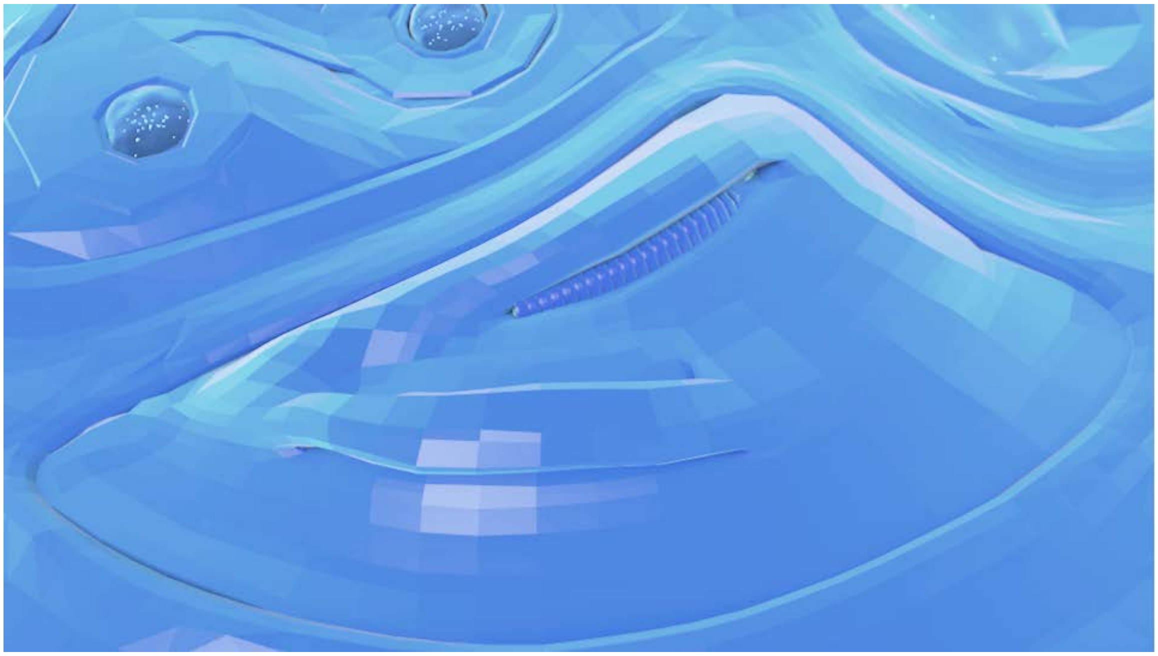


Fig. 4.31

This is a default representation of the zone of study and research. From this top-down view, we see that the user can enter in through the side and there are two main surfaces that the individual can come into contact with through physical touch with the rest being smooth areas of open space. When thinking in terms of a mixed reality setting, designers must then about areas of the interior with intentionality for passive haptics. For instance, this area is akin to an office or study so there will most likely be a lot of word processing to take place among other research and study-oriented tasks. Most keyboards in an augmented reality setup are natively virtual but in the long term it might be more comfortable for users to feel the sensation of touch a surface while typing. The long-extruded strip in the center of the area suits these purposes for passive haptics of virtual typing for drawing.

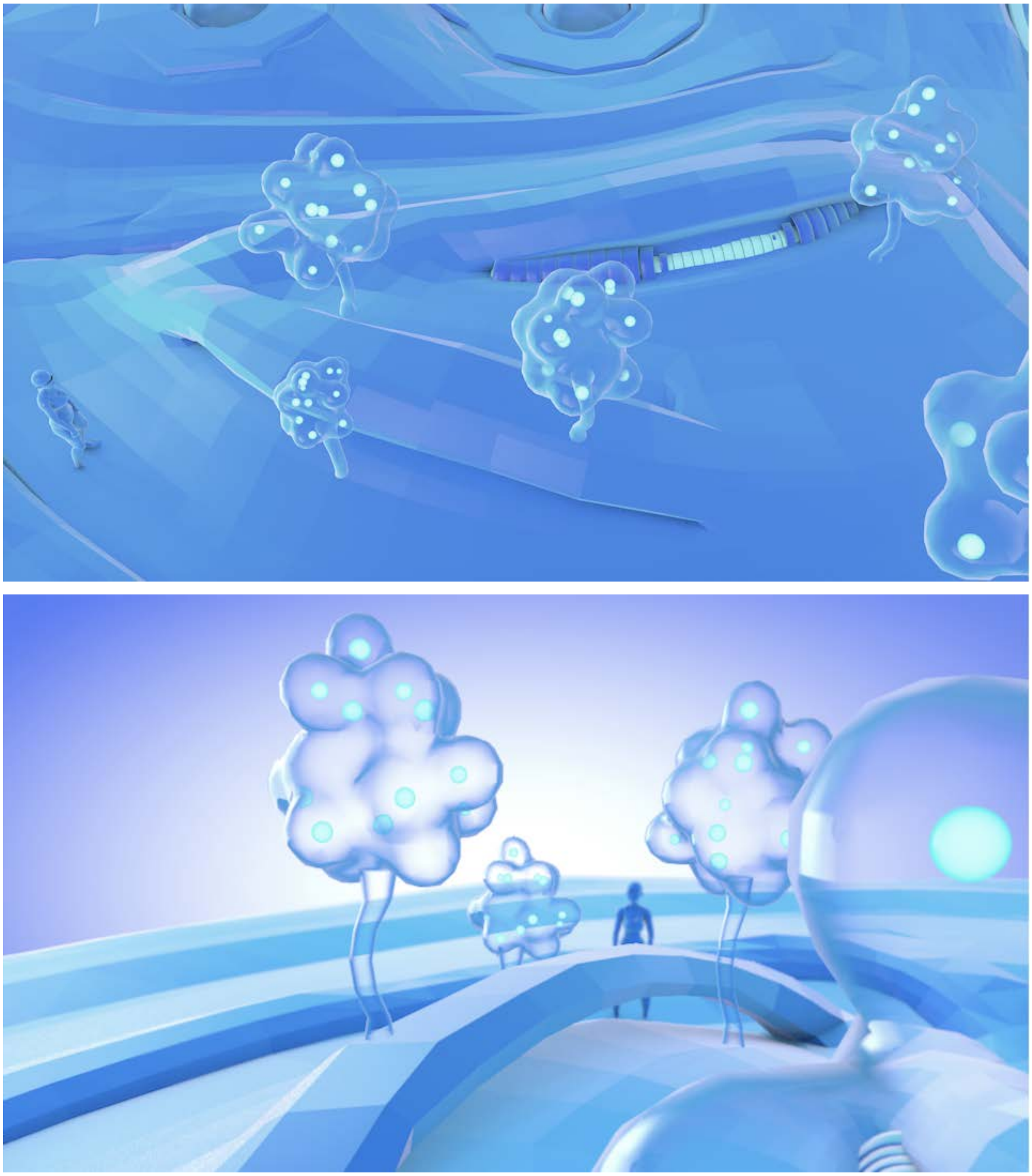


Fig. 4.32

In this next series of images, we see that the user has entered the spaces and there suddenly appear these virtual tree-like structures akin to the alveoli

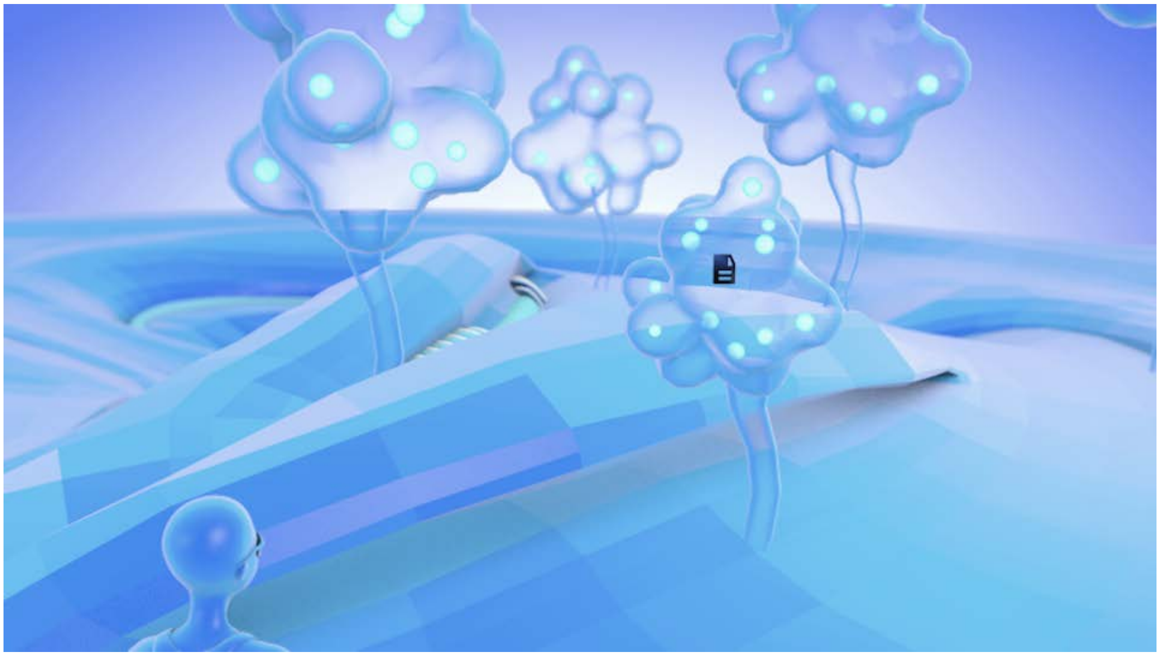


Fig. 4.33

Fig. 4.34

inside of the organ of the lungs which is the metaphor for the area. The breath of life of new insights and information. Within each of these alveoli structures are energy sphere which represent spaces where the user can customize the area by placing commonly used assets, programs or icons

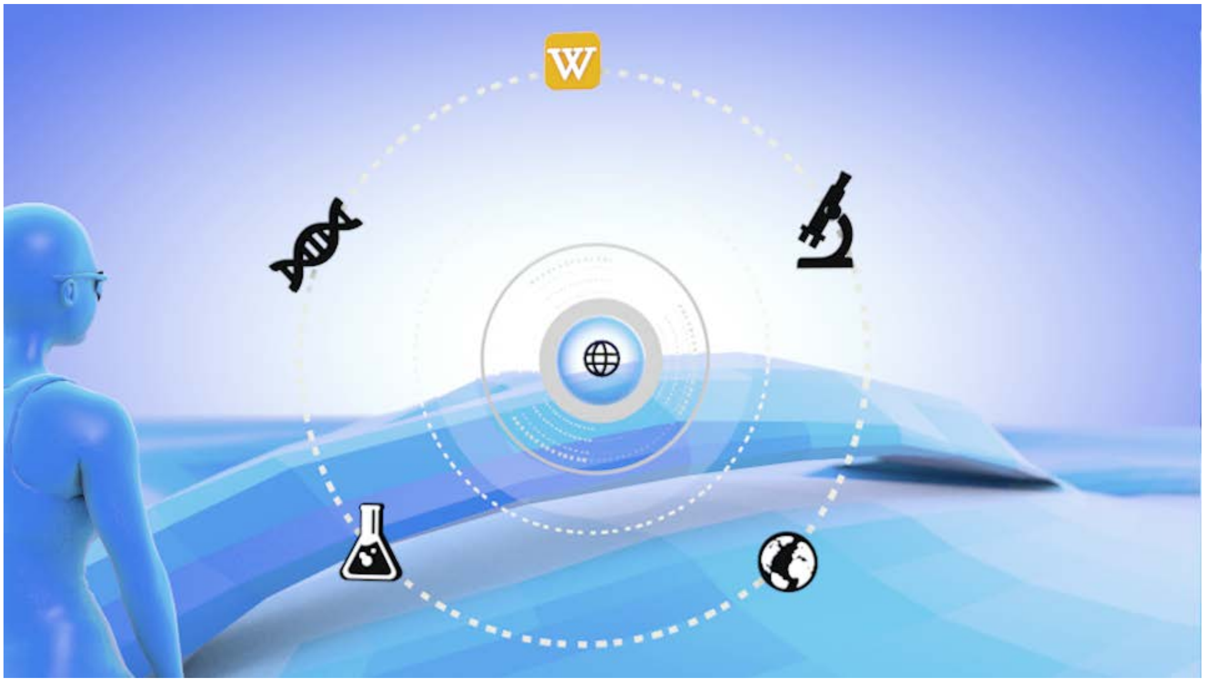


Fig. 4.35

for easy access in the space. This calls attention to the notion that virtual structures can also be placed in a zone that contributes to the visual aesthetics of the space while also being functionally practical. In this instance, the zone's default icon is placed on one of the nodes of a tree in this space. The user selects the air sac with this icon and then it expands out to display the primary functions of the space. These include, word processing, web access/scientific simulation programs, eBooks, imagery, and mail/communication. The user selects the web access/programs function and then the ring collapses then expands to reveal more options in which the Wikipedia link is chosen.

Once it is chosen a virtual keyboard appears projected onto the zones surface for typing and passive haptics along with a figural viewscreen popup of the traditional webpage view. The user enters the search term hexacoralia and then the result entry webpage appears. Something important to remember when designing for mixed reality is to revisit the notion of variability in spatial scale when designing interactive environmental experiences. Just because there exists the potential for the webpage to be full immersive with information scattered the panoramic, environmental or vista space of the interior doesn't make it necessarily relevant and appropriate in every instance. In this case, the user simply wanted to search for information about a subject and access it quickly all in one space, so the conventional single screen format was suitable. If more complexity was necessary, the user could even summon multiple screen to tile throughout the space and different sizes and levels of magnification.

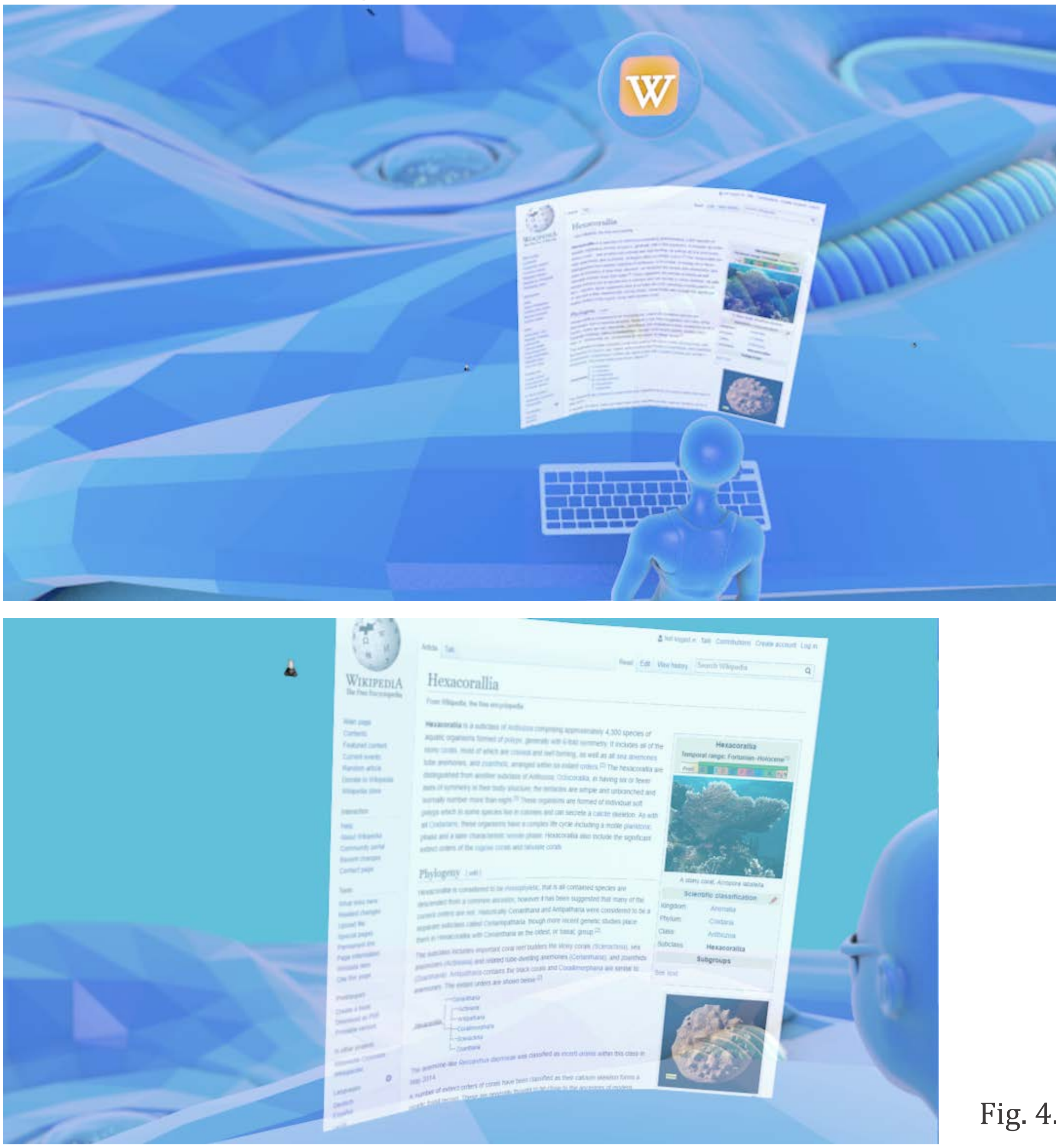


Fig. 4.36

The user is satisfied with the information culled in this format however would like to examine the attached media in a more immersive format to gain a better understanding of the subject. The image the underwater sea coral is selected and then 3D models of this scene project into the user's space with selectable individual elements for additional context information. This feature is particularly useful for someone who has a visual hands on learning style or even for classrooms children and educational institutions. It brings another dimension to learning by along the user to walk around and experience the contents of the information contain on the website in a 3D format.

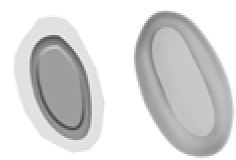
Presently, there is much development being undertaken in volumetric media capture which could enable these types of experience of web media. Also, designers working with immersive content creation could add mixed reality adaptivity to web sites and content. Mixed reality isn't simply relegated to enabling a simple screen to float in space from varying angles but should be inclusive of interrogating the dimensionality of the spaces and making the media content adaptive to the tasks as well as the environment at hand. The job of 3D designers extends beyond being pigeon-holed to the video game, simulations or entertainment industries into becoming a part of crafting ubiquitous next generational interactive experiences on the web and other forms of mixed augmented reality interactive media.

This is a small example of the possibilities of a website inhabiting and being adaptive the user's space and manipulation tasks.

Fig. 4.37

4.2.4 Zone of Social Interactions

Table 4.4

THEMATIC MODULATOR/PURPOSE/GRADIENT	INPUTS/OUTPUTS (Context Specific)	SPATIAL ORGANIZATIONAL SCHEMES
PURPOSE: **Fostering connectivity through mediated and unmediated social interactions** SCALE MODULATION: **Panoramic + Figural + Vista** THEMATIC MODULATOR: **abstract heart beats and pulses for the things we love about people through social connections, media experiences and entertainment** ****(Fixed Spatial Modulator by default because of zone specificity but also capable of housing Swarm Entity Modulators)* GRADIENT: **Intermediate**	INPUTS: • Passive Haptic Feedback Props/Homewares • Virtual Keyboard • Depth/RGB Camera Sensor • User worn sensor ring + peripherals • Wireless Controller OUTPUTS: • See Through HWD • Environmental Haptics • Speakers	• Network – CS • Space within a space – SR • Space linked by a common space – SR • Clustered Strategy – SS • Grid – SS 

Social media and modern technology utilized for interpersonal communicative purposes has made excellent strides in the past twenty years to bridge the gap between people of varying backgrounds, locales, social classes and cultural groups through varying online forms of exchange. There is however a lot of information and critical points of conversation lost in translation through these digital mediums that utilize only a single or a few sensory apparatuses of the user. Additionally, many of these forms of exchange mediated through a user's smart phone keep the individual further disconnected from the people in his or her surroundings by being focused constantly on the device.

The Zone of Social Interactions introduces designers to the possibility of utilizing augmented reality in addition to or in place of common methods of digital exchange. Unlike these limited norms of messaging a 3D user interface in a mixed reality environment opens the user up to more visually immersive forms of exchange through in the first respect by blending both the physical and virtual worlds during communication so an individual is not solely focused on the digital. This is possible through utilization of the either the optical or see-through head worn displays that the user is equipped with in the environment that allow for this blending to take place. On the most basic level, the user can now be cognizant of their surrounding and its inhabitants while also typing a message via a mid-air virtual keyboard, or voice to text along with executing any other desired media functions. Augmented reality interfaces also open the possibility for holographic video chatting in 3D which would allow for more impactful interactions between user. Inside out tracking on the head worn displays and or in addition to sensor camera inputs installed in these hybrid environments that consistently scan the layout along with inhabitants allowing the rendering system to capture a Realtime body scan of the user to be visible in 3D communications with individuals that they are communicating with in a mixed reality setting. This is akin to having the person you are talking to physically occupy the same space only it is their rendered virtual representation. This moves media communication efforts a step closer to a greater sense of immersion because users can pick up on body language and facial expressions along with the voice.

Developing augmented reality programs of this nature would foster greater connectivity between subjects while not creating a schism forcing users to choose between the digital or the physical because in mixed reality interfaces, both these elements occupy the same space.

Another design goal of this realm is to encourage relaxation, leisurely discovery of fun games, music and media items that are also part of social exchange. This zone includes applications for 3D and traditional messaging as described above in addition to web browsing along with options to play games music or film from the context of 2D screens or spatially augmented projections.

Keeping in alignment with the organic/biomorphic aesthetics of the interior, the interactions and graphical features of this space have been modeled after the abstracted metaphor of the human heart. The shape of the space represents a cavity of such an organ in which the blood flow is the people and the media communications. Accessing UI elements in this space include interacting with the icons in the AR blood flow water to trigger certain menus or interface functions.

The aesthetics also play a role in influencing the zone's design of the passive haptic feedback homewares objects installed in the realm. Although this is no included in the illustrations below, conceptually, Heart valve cushions serving as poufs, pillows or seating occupy the space as an alternative means of accessing UI functions while also serving practical as well as decorative functions. The traditional wireless gaming controller is another specialty input of this zone as it affords the user more precision in making movements when engaged in gaming applications.

The organizational scheme utilizes the same spatial strategies as the other realms except for its own brand of the clustered spatial strategy. The clustered strategy is utilized in this social living room zone because the parameters of the layout type lends itself to leisure, meandering and playful discovery of features in the interior space. This strategy translates on the UI level into having elements of interface loosely scattered around the spatial volume. Although, each virtual element possesses its own internal symmetries, media gradients and modulation functions to bring order within this seemingly non-structured interior layout pattern.

The media gradient of this zone is intermediate because users within this zone are afforded varying opportunities to engage in applications geared towards play, relaxation and socialization. Having a modulate balance of options and user interface complexity keeps the user engaged with the discovery process without being overwhelmed with too many options which would defeat the design goals of this leisurely zone.

The site-specific modulating UI elements in this realm are abstract virtual arteries and veins that serve to store, expand or execute various application functions.

4.2.4.1 UI Interaction Features

0. Mixed Reality Globals – Component 

Mixed Reality globals is the default menu set embedded within every zone of this interior. It allows the user to perform operations essential to the function and maintenance of mixed reality environments such as saving or recycling media assets, sharing applications, user preferences and setting, templates, linking and other tasks in this vein.

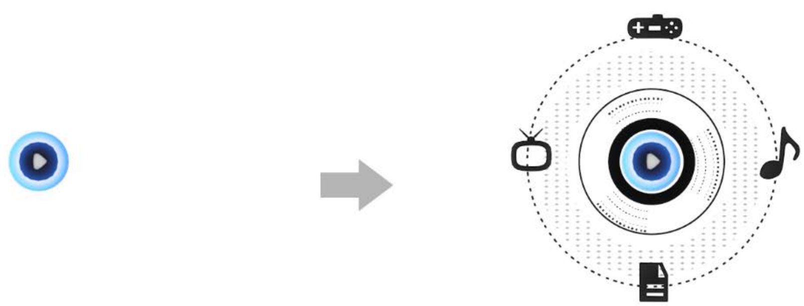


Fig. 4.38

1.

The main function of this zone is play because it encompasses all social and leisure activities. Once this option is activated, rings are expanded to display social media, video and musical playback options.

2.

When the video option is selected, the previous rings get smaller and nest within the interface while a third ring expands to reveal more video playback options.

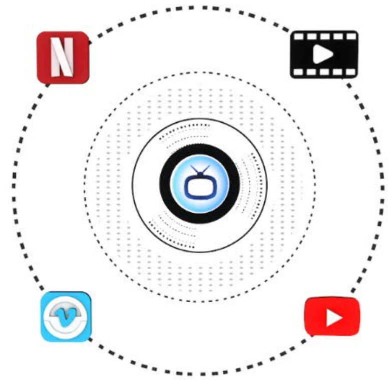


Fig. 4.39

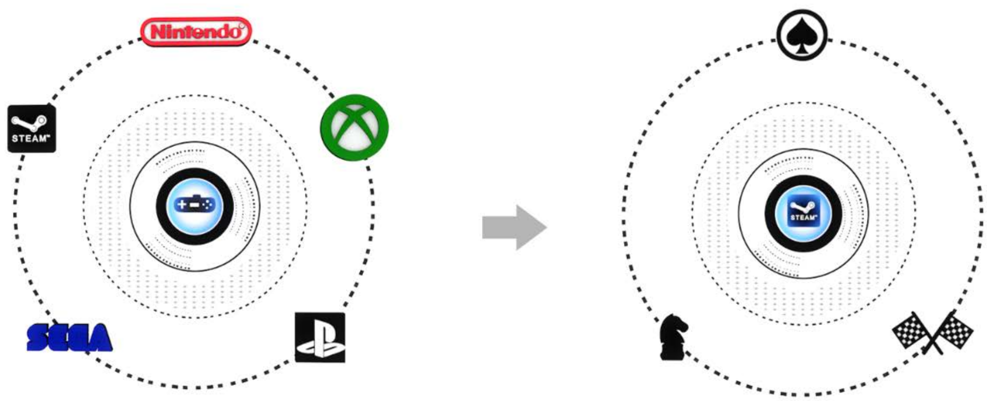


Fig. 4.40

3.

If the user selected the gaming icon, this third ring would appear and then dependent upon the installed systems and games, a fourth ring expands to show more gaming selections. In the above example, the user selected steam and then the installed default mixed reality games were spades, chess and a racing/puzzle game.

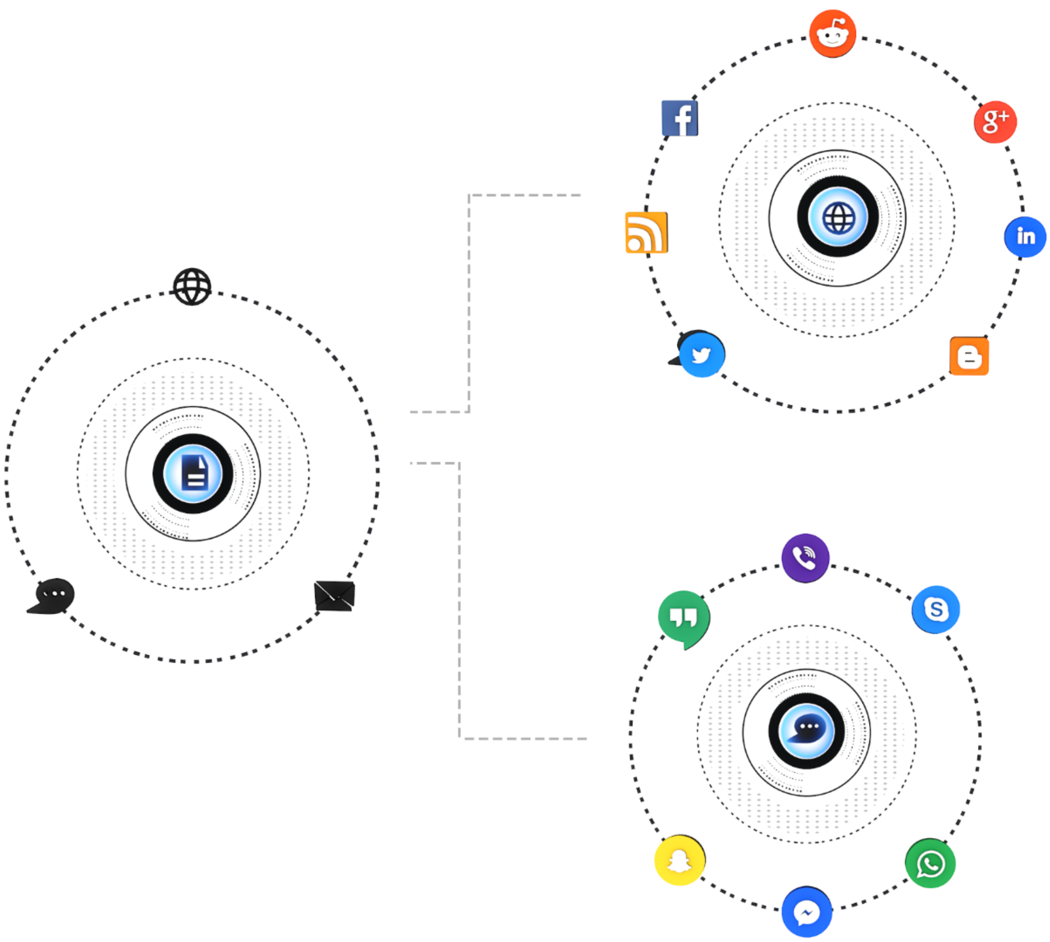


Fig. 4.41

4.

The third option, social media was selected in this instance and the sample diagram shows a few of the possible wireframe of options present for this function which include web perusal, messaging and email sharing.

4.2.4.2 Integration

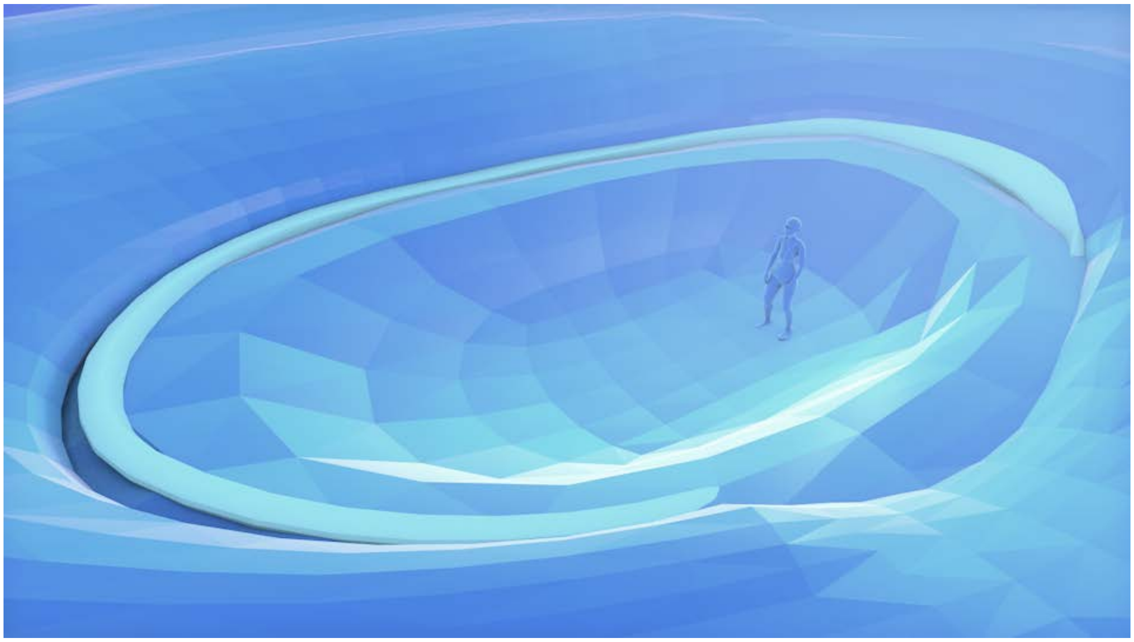


Fig. 4.42

The visual metaphor for this area dedicated to social activity is a heart that beats for things people and places that we love. The area is shaped like a simple basin or cavity with the people along with mixed reality content being circulated and pumped through as the life blood. Here we have a single user standing inside this naked space before any augmented reality overlays have been activated.

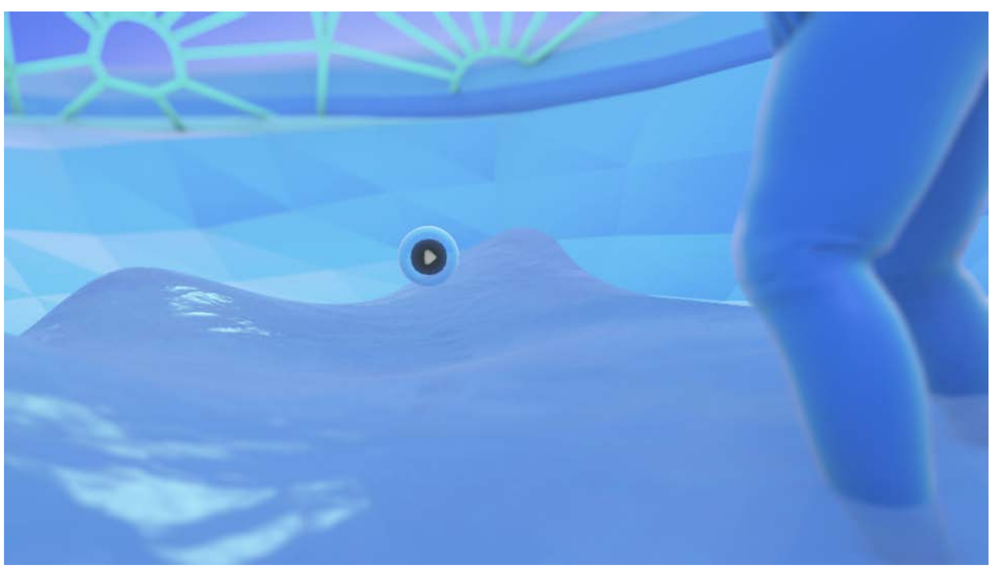


Fig. 4.43

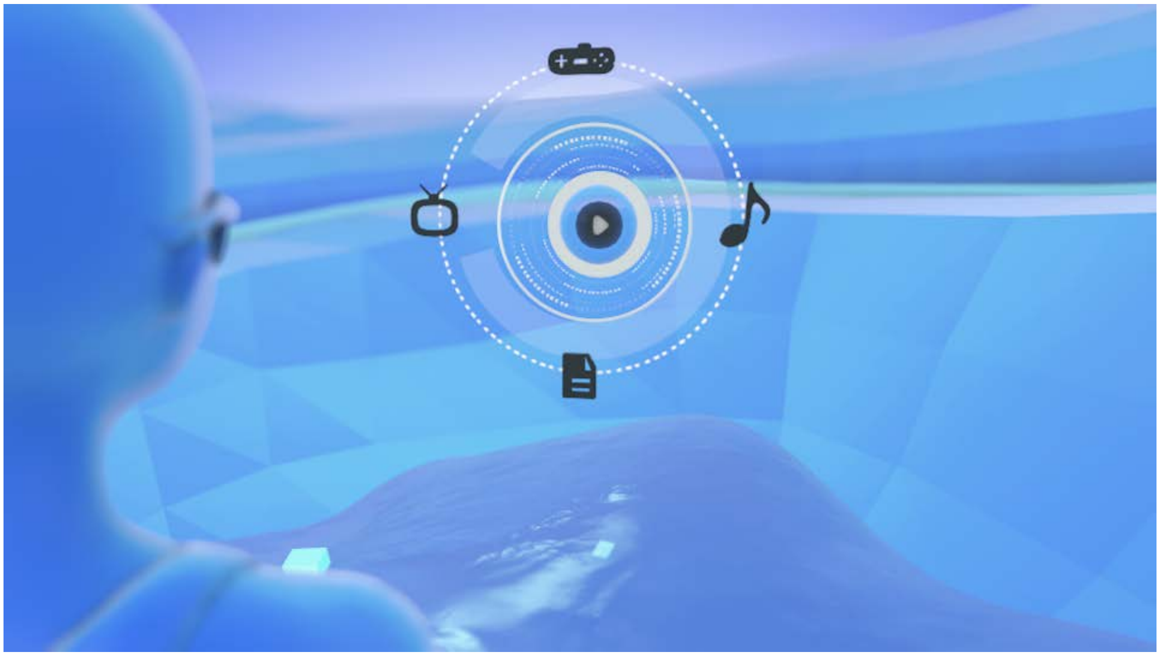


Fig. 4.44

Once activated, the basin fills with augmented reality water and all the accessible icons and functions are swimming or idling as fish beneath the surface of the

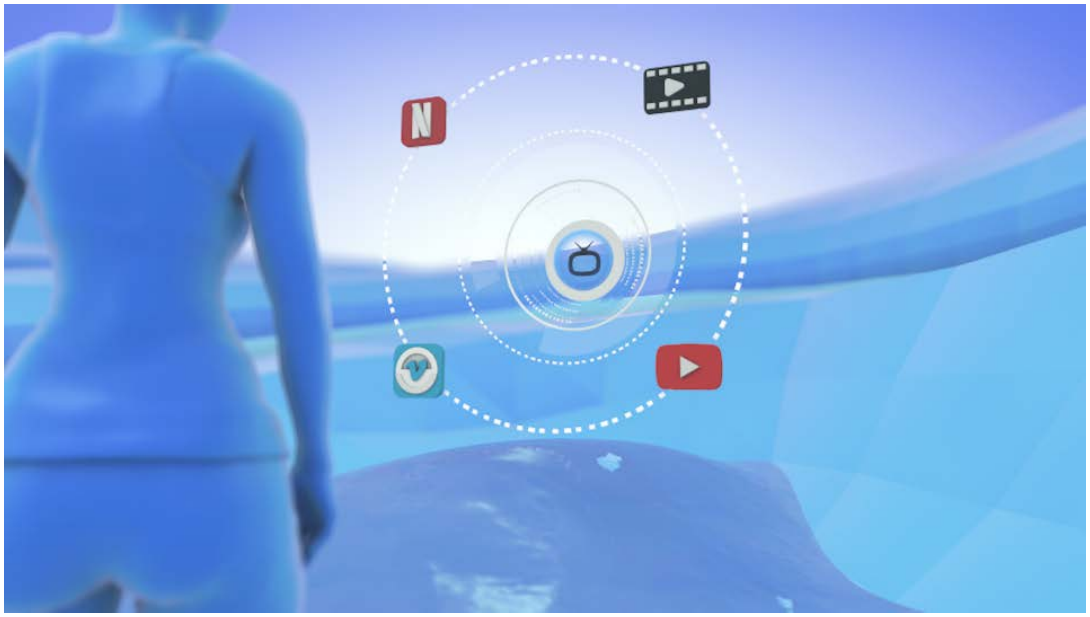


Fig. 4.45

mixed reality wading pool. The primary play icon for this social zone is selected and then it rises from beneath the surface into mid-air and then expands to display outer rings with more options. These options include. Gameplay, music, video, messaging along with social media. The video play back feature is chosen and then the primary ring shrinks to expand a third ring showing different playback options. Vimeo is chosen, and this terminates the primary UI sequence through launching the program via a virtual carousel of images.

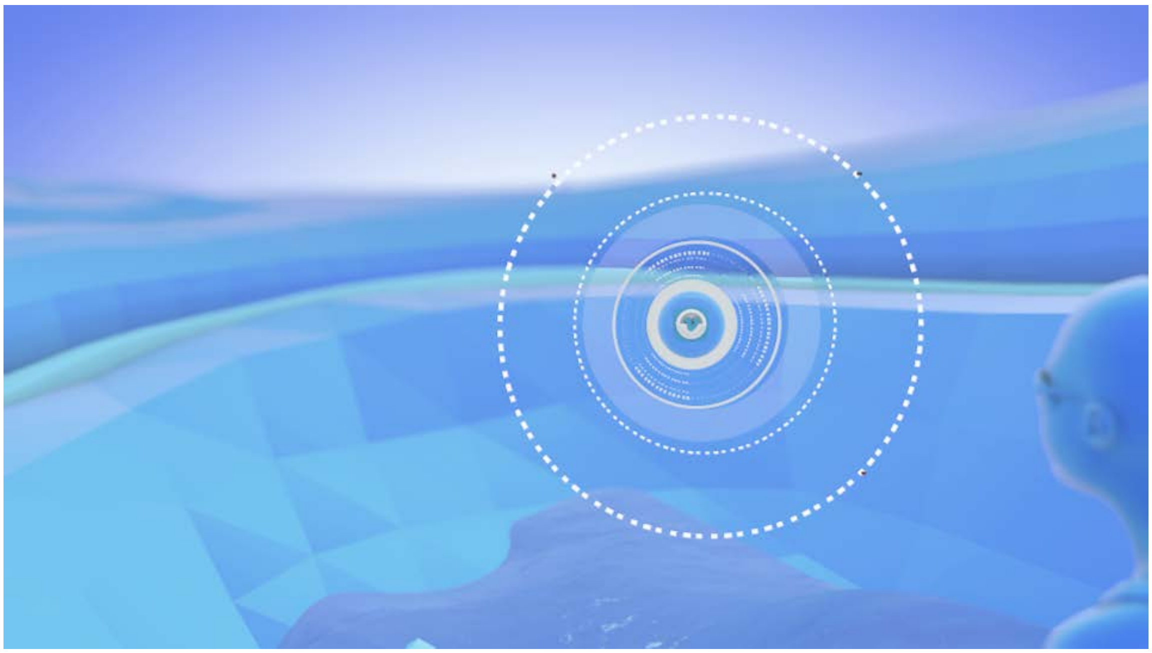


Fig. 4.46

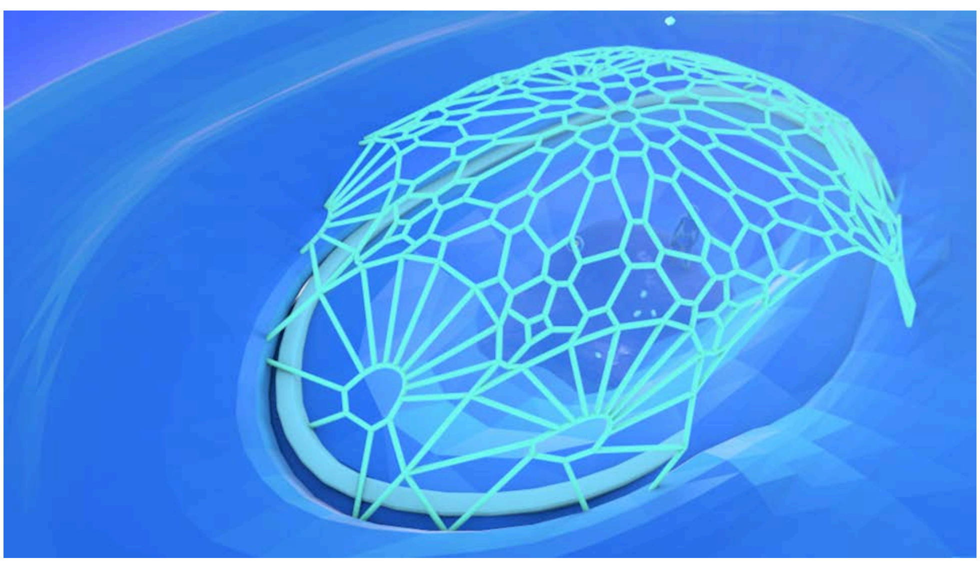


Fig. 4.47

Fig. 4.48

The user can position this carousel anywhere in space through dragging the blue hotspots on the AR water anywhere in the zone to scroll through and select media content to view. A virtual lattice overlay has also appeared above the zone while this program is active to aid the user with selecting points to distribute video screens throughout space. The below illustration shows two videos which have been chosen sized shaped and positioned in the space. This is just one way to present video in space. We saw in the

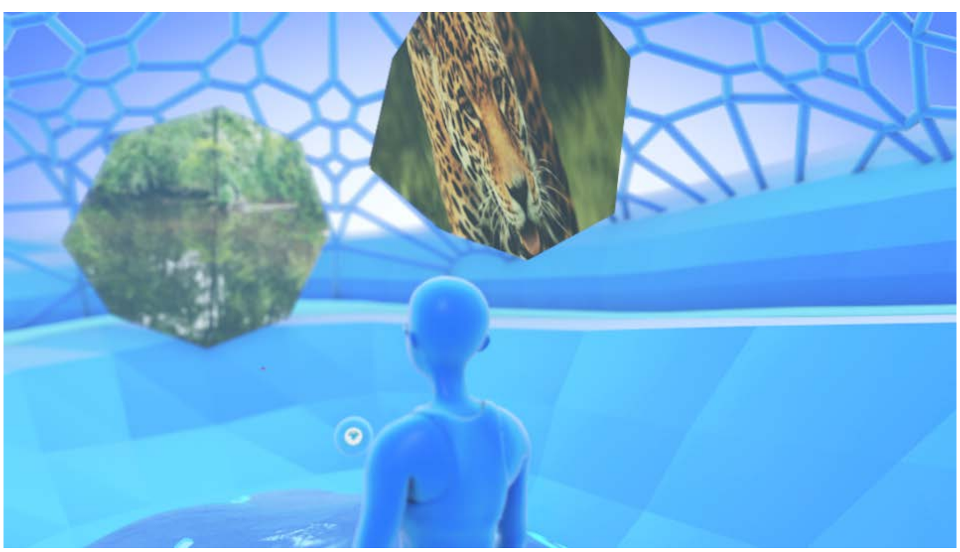


Fig. 4.49

previous section about the inclusion of 3D volumetric video along with 3D media/ imagery for web pages but in this instance, we have taken more of a traditional flat screen approach which could be perfectly acceptable or preferable in some instances. The elements for good design in mixed reality include consideration for variability and scalability in the media content created as there is never any one size fits all solution for experiencing dynamic media in varying interior configurations.

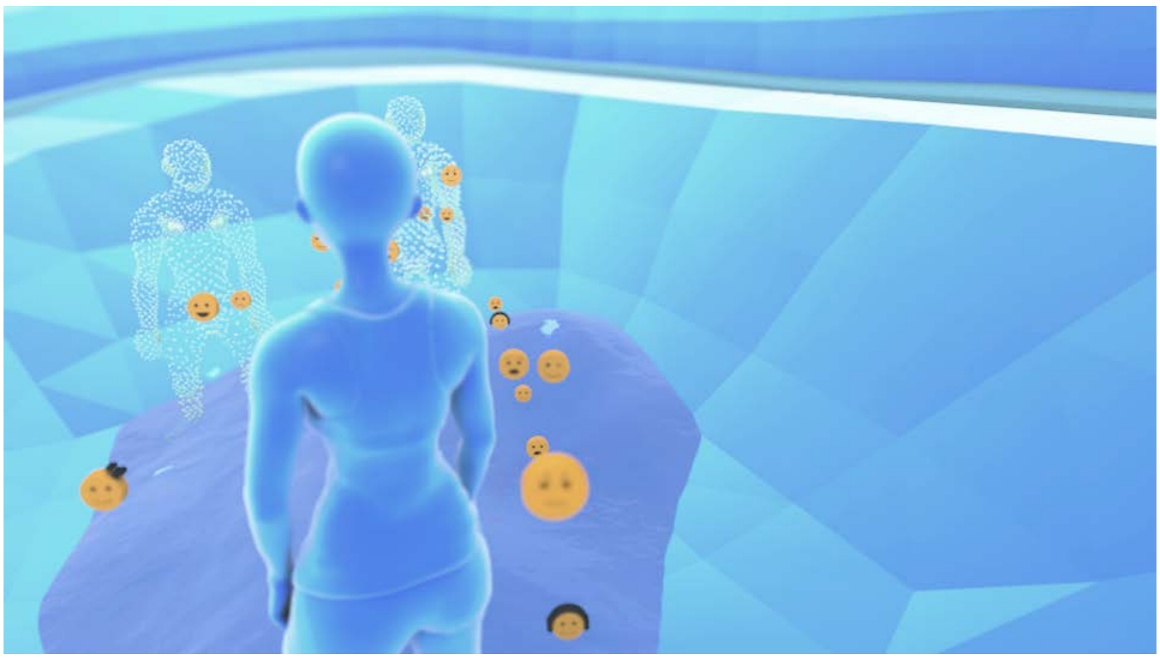


Fig. 4.50

Additional functions for this social zone mention in the UI wireframe section include accommodation for game play, telepresence and messaging though social media applications. The above figure demonstrates telepresence through messaging replete with emoji exchange. The user is physically present with two virtual friends and they can talk to

Fig. 4.51

each other just like they would in real life, through environmental texture, gestures, emoji or a mixture of many forms of communication.

The last couple of illustrations demonstrate how the user can socialize and interactive as it pertains to immersive gameplay. We have an instance of virtual chess with a virtual participant and long with a car racing/puzzle game in which the user can distribute the tracks through out the entirely of the space while there can be participants in VR at a local or remote location driving the vehicles as the AR user creates and manipulates the tracks in real-time. These represent a few of the many possibilities that mixed reality can be utilized for leisure and social activities.

Fig. 4.52

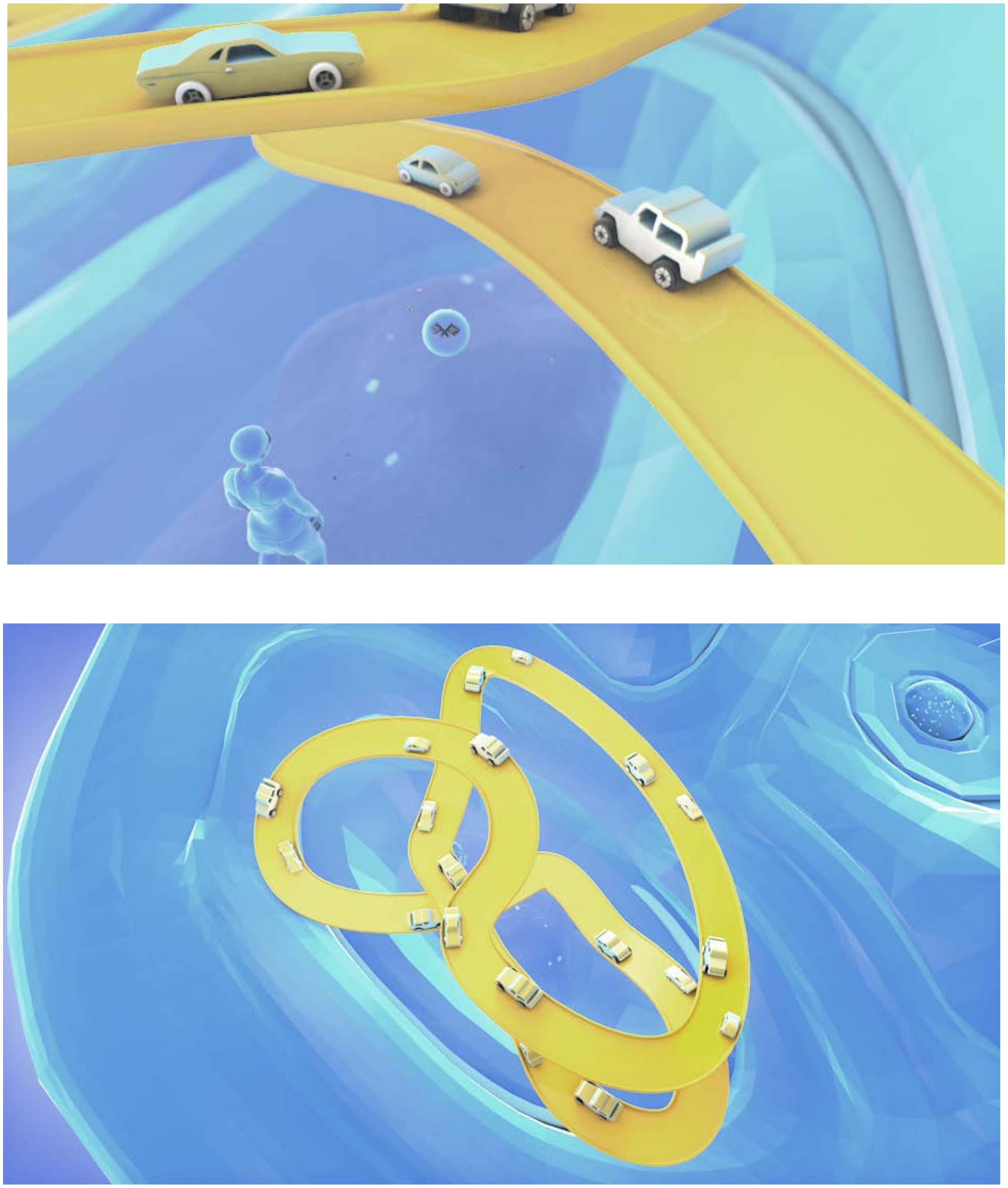


Fig. 4.53

4.3 Construction of Mixed Reality Space

This section serves to tie in all the previously learned concepts and design discovered elements into a general step by step instructional guide summarizing the process involved in creating any mixed reality space.

Fig. 4.54

1. The interior of environment is either constructed or retrofitted from previous structural layouts to be biomorphically continuous in form on all surfaces to mirror the organic quality of the virtual life moving through it. For mixed reality environments, digital media, information, animations, media and assets are this artificial cellular life substance and the physical presence of interior is the entirety of the organism. Regardless of the layout or purpose of the interior, it would behoove the composition of all mixed reality spaces to create these continuous, fluid spatial structures to house and interact with virtual forms because it embodies the principles of infinity and not-separateness. These

essential elements of these hybrid environments aid with user immersion into the augmented reality world with design features virtual and physical dovetailing one another adding towards user comprehension of the space rather than dissonance. Sensor cameras are positioned at varying angels in the environment along with the initial placement of environmental haptics and any other relevant smart devices or processing systems. The user is also outfitted with their default visual input and systems control output devices for functioning in this augmented reality UI. These devices vary and are ultimately determined by the design goals of the space. In the example conceptual mixed reality environment of experiential learning, discussed above it was decided to use a see-through head worn display, along with user worn sensor implements for inputs/outputs but the options are variable.

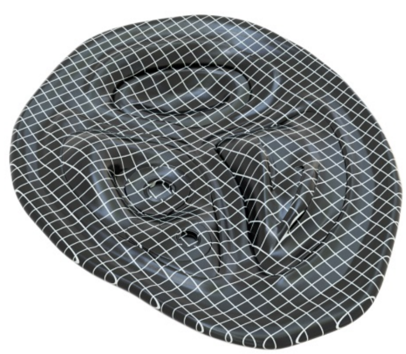


Fig. 4.55

2. The user interfaces with the default systems UI called the Mixed Reality Globals discussed in previous chapter to manage user profiles and general settings. On

this end, passive environmental depth and rgb sensor cameras scan the layout out of the interior and the computer system establishes an overlay virtual grid

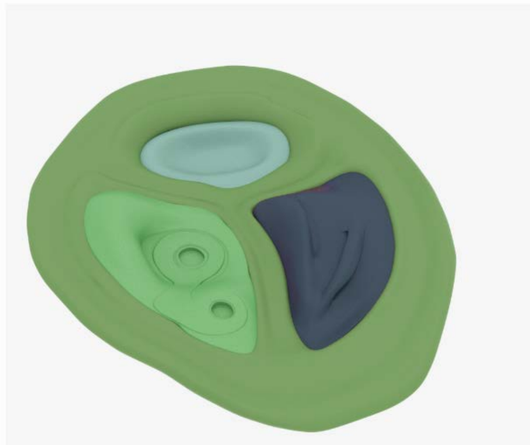

Zone Designation

Fig. 4.56

coordinate system for the placement and movement of digital assets among other functional purposes.

3. A World in Miniature digital miniature of the environment is created as a control hub that the user can draw and fill in areas of varying virtual/physical/spatial designations. Zones are demarcated by the designer utilizing user interface selection and coloration tools.

4. Applications and interaction routines are installed based upon spatial orientation and according user affordances and constraints. The designer either manually installs these programs or they default based on spatial organizational schemes. These installations can also include any additional input/output devices beyond the defaults like smart rings, glasses, passive haptic feedback homewares or soft goods. For example, there, a circulation pathway will feature

by default a modified UI layout that is optimized for readability when a user is in movement which differs from another area where the user is primarily sedentary. A smart pillow or a home décor item are examples of home or interior wares that can be installed and interacted with to control functions of the augmented reality 3D user interface.

5. Environment is now ready for perusal of users outfitted with appropriate input/output modalities. Something important to note about all these processes is that the user is not expected to go through these steps or even a fraction of them each time they occupy a mixed reality environment. Most of these steps are relegated to the work of a designer and all the user needs to do is install their pre-made or custom templates for their own interiors.

5. EVALUATION

5.1 Design Pattern Evaluation

The purpose of this design research endeavor is to establish connections between seemingly disparate veins of design and other subjects of study to aid in the creation of a framework for mixed reality interiors. The successfulness of this endeavor lies in the quality of relevant correlations that were made at the archetypal level of principles from which paradigms of design modalities originate. Another measure of success is its ability to stimulate further lines of inquiry and impetus for researchers and developers to conceptualize discovered potentials. This research project is relegated to the scope of analyzing and connecting these fundamental building blocks and conceptualizing inherent possibilities through design experimentation, simulations and brainstormed opportunities for development deriving from background research into augmented reality, user interfaces and interiors. This level of granularity forgoes the necessity for user testing or more finely tuned production processes as it provides a conceptual basis for such prototype generations. Section 5.2 of this chapter will discuss some of these possibilities discovered.

Digital media along with interior design principles and fractals which are nature's organizing principles were compared for their commonalities and five building blocks of mixed reality environments where derived along with questions that designers should ask during the creation process. This will help prioritize generating a balanced physical/digital interior layout from conception to completion with iterations thereafter.

The objective is to create augmented reality 3D UI systems and interior arrangements that complement each other compositionally so that the user can perceive the interrelations of the zones in spatial compositions to achieve a phenomenological gestalt of the of the environment and its purpose, instead of only individual sections.

To reiterate, the five properties of fractals were utilized because the mixed reality environment in many respects is an artificial simulation of the natural world. It is an endless flood of life blood that is akin to digital media that inhabits, moves and interacts within the body of the organism or ecosystem which in this case is the interior composition of buildings. Nature does an excellent job at organizing complex environmental information into pattern languages that generate positive psychological feedback in humans according to research findings conducted by cognitive scientists and psychologists. [23], [24] Resultantly, it makes sense to use fractal properties as a foundation for designing these hybrid restorative spaces while also being open to making design modifications as needed during later iterations of the planning process.

Below is a design pattern evaluation chart to aid designers during the process of developing concepts for mixed reality environments. On the left is the fractal properties and their correspondent digital media and interior design principles. On the right, is a series of questions for evaluation. Following this chart will be an explanation of how these principles were integrated into the simulated mixed reality conceptual environment presented in Chapter 4, Implementation

Mixed Reality Design Pattern Evaluation Chart

Table 5.1

FRACTAL PROPERTY//ARCH DESIGN PATTERN//DIGITAL MEDIA PRINCIPLE	DESIGN PATTERN INTEGRATION EVALUATION
FRACTIONAL DIMENSION/ ROUGHNESS + GRADIENTS/ NUMERICAL REPRESENTATION	** How are media asset gradients and modulators determined by affordances and constraints of spatial orientation + overall interior mixed reality theme? Is the level of digital and physical complexity intermediate or at least commensurate with design goals
INFINITY/ NOT-SEPARATENESS/ TRANSCODING	**Designers should consider the UI and media assets network of connections within and interior layout. How does the form and structure of the interior relate to inhabiting media forms and vice versa? What is the binding element of not-separateness in the mixed reality composition? How do media assets translate or change shape or form in the UI network into in accordance with spatial zone orientation?
RECURSION/ ALTERNATING REPITITION/ AUTOMATION	**How can self-referencing automatic functions in the 3D UI be integrated to optimize user experience or used to generate prebuilt templates to organize media assets
SCALING/ CONTRAST + LEVELS OF SCALE/ VARIABILITY	**How do the areas or zones of a mixed reality interior relate to the entire environment content wise, geometrically or visually? How does the position and structure of the forms in the spatial volume affect the scaling, adaptations or variability of media assets present? How does these scaled points of contrast aid the user in determining their orientation in space virtually and physically?
SELF-SIMILARITY/ DEEP INTERLOCK AND AMBIGUITY/ MODULARITY	**How can the design of graphical UI layout in addition to selection and manipulation functions maintain self-similarity at varying levels of scale to aid in user comprehension of interface? How do changes at one level of self-similar scale change to affect all others? What types of shapes or geometries can be utilized for greatest cognitive benefit for users in accordance with design goals of the space?

5.1.1 Mixed Reality Design Pattern Considerations

<u>Fractional Dimension</u>

The media asset gradients or the level of complexity of UI elements and menu items are determined by the interior's thematic function which translates into the design organization schemes mentioned in Chapter 3 called spatial strategies along with its associative cognitive affordances and constraints. Within a specific area of the interior, the media gradient can sometimes also be modified by the spatial features, which ties into those strategies in addition to the user's custom settings.

As a rule of thumb, environmental psychology research has shown that human subjects have an overall preference for being in environments with an intermediate fractal dimension or levels of complexity. The reported range includes 1.3-1.5. Weighing these factors in mind in addition to the spatial strategies provides a sound basis for research approaching the implementation of gradients and how they are determined and utilized in a mixed reality space.

From the implementation chapter, the fractal dimension of the varying zones in the interior was determined by the functional purpose of those areas along with the spatial strategies employed therein.

For example, in the zone of social interactions, which is geared towards leisure and recreation types of activities, many different spatial strategies were employed the most prominent being the clustered strategy. This layout is about encouraging a sense of exploration in the user as well as evoking feelings of comfort and relaxation. To suit this purpose, the physical and well as media user interface features when programs are executed are spread out in a loosely organized fashion with the level of complexity in terms of functions available relevant only to the purposes of recreation. If the user were to go into the UI settings, they possess the ability to customize the levels of media asset complexity beyond the defaults to taste. For example, the user might want quick access shortcuts to their favorite media items and therefore alter the settings to make them always visible or maximized in the space thereby altering the fractal dimension or level of complexity of the space. They can also place the asset wherever desired and additionally be able to organize a multiplicity of them in to graphical templates that serve as decorative and functional features in the mixed reality space. This is an instance of a user customized fractal dimension. Another layer of research for implementation includes discovering the types of templates that can be used in augmented reality spaces that feature an intermediate fractal dimension for enhancement of the user's experience.

Infinity

Infinity is determined by how the physical spatial features along the UI functions are translated, relate, and are networked with each other in the varying zones of the mixed reality interior. It's important to construct an environment with a fluid design language for the sake of readability and enhancing the user comprehension of their surroundings, the interrelations and interactions possibilities. If the interior layout and core user interface manipulation functions vary too much within the context of a single interior environment, this would not create the most desirable and efficient experience in in terms of ease of use.

In the conceptual environment, in the implementation chapter, the design of the physical features mirrored the properties of the inhabiting media. The spatial forms were smooth and continuous similar the continuous nature of the augmented reality media updates and changes. Infinity was also created in this mixed reality environment by utilizing the same core interaction themes from zone to zone. All zones possess the ability to have media assets selected, accessed, manipulated or modified according to user preferences. The input and output modalities were standard for each space at the generalized level with specialized devices or functions coming into place only when the purpose was relevant.

These similarities along with the ability to transfer UI features or applications to other zones at will comprises another instance of the implementation of infinity.

Recursion

Recursion in mixed reality interiors translates into the user interface possessing the ability of automation for repetitive functions for purposes of making certain tasks and the user experience more efficient. Organizing media assets or user interface features or automating frequent selection and manipulation tasks in digital/physical space are some of the plethora of functions that automation could help with. Designers are encouraged to seek new avenues through which this property can be applied to enhance the user experience of the augmented reality space.

In the simulated environment showcased in an earlier chapter, automation was implemented in every zone in a slightly different context. In the creation zone, various templates and modes of interaction became available after the imagery app was accessed. This included the abilities to conformally map imagery to the spatial features of the interior, or dynamically place them into customized or preset grid and kaleidoscope arrangements among other possibilities. Additionally, upon selection of such an item, the asset will automatically maximize in the direct field of sight of the viewer rather than the user having to manually scale and position the media.

Scaling

In addition to the initial evaluation questionnaire, the scaling fractal attribute will include a specialized set of evaluation considerations because it is the main driver influencing the interaction and expressive representations of all other properties. The below chart of evaluation questions has been culled from Barba's mixed reality spatial scale research endeavors and should prove useful for developers and designers moving forward with refining prototypes in this vein.

Spatial Scale Evaluation

Table 5.2 --[30]

1.	What are the representational elements of the experience at each scale? (What is being represented and how is it being represented?)
2.	What are the interactive techniques at each scale? (Manipulation, perspective changes, simulated locomotion?)
3.	How do interactive elements match or mismatch with the scales of the representations? Are these productive or confusing?
4.	How are boundaries between scales depicted and/or operationalized?
5.	How are transitions between scales across boundaries accomplished?
6.	What sensory cues (visual, audible, tactile, etc.) are present and how might these likely be interpreted?

Scale serves to provide a sense of contrast enabling the user with the ability differentiate where they are in space as well as tying into the property of the fractal dimension with the modulated levels of detail. Affordances and constraints as well as the spatial layout and design goals of the area determine the scaling of the mixed reality 3D user interface elements.

In the simulated environment of chapter 4, the sizing of certain UI features was increased in the circulation zones to improve readability while the user is in transit, as it would be more difficult to try to interact with smaller icons or text. Another use for scaling across the whole environment is as an indicator of status updates or other current messages that might serve as a visual cue to get the user's attention. The icons or media assets would then diminish in scale once their message had been reviewed. The user also has manual control over the scaling of media assets and this is useful in the study/research as well as the creation zone areas of the concept environment because it enables users to enlarge and examine 3D models for educational or design purposes.

Self-Similarity

Self-Similarity dovetails the previous property of scale because UI menus and templates along with gesture-based controls and functions behave and are graphically similar across the range of scales. Additionally, if a change is made to a function at one level of scale then all the scales will be affected to reflect this modification.

This property allows the user to familiarize themselves with the user interface of a mixed reality environment and navigate at any range of depth and remain familiar with the interaction possibilities without having to learn a new system.

An example of this in the test environment was the general 3D UI menu system that maintained a self-similar nature of the icon spread through various layers of selection traversed through. If graphical templates or selection settings were altered, each of the layers of icon spreads and functions in turn morph to reflect these changes. The default menu layout of each of the zones in the evaluation section, maintain self-similarity in the use of interaction features while traversing through the menu item. This way of designing interface interactions provides an introductory holistic framework for easily understandable user experiences.

5.2 Discovered Research Potentials

5.2.1 Mixed Reality Design for Physical and Psychological Health

One might ask the question as to why it is necessary to balance the digital as well as physical aspects of the design?

Referencing back to the Poetics of Augmented Space journal article listed in the media design considerations chapter, the concern of digital media forms drowning out instead of complimenting the features of physical space was brought up. [1] From personal observations I can see this becoming a compounding issue if left unchecked. In current times, people devote the utmost attentional focus to their smart phones and devices whether indoors or outdoors to the exclusion of maintaining awareness of invited company during social outings, environmental features, and substantive non-digitally mediated connections to other humans. This could negatively impact one's safety and health physically and psychologically because people might not be getting sufficient amounts of exercise or enter potentially dangerous situations while on foot or driving because of the lure of the digital media and status messages that inspire forgetfulness of the surroundings.

[23] Social skills could diminish or not even form correctly in developing youth because of lack of exposure to critical interpersonal growth experiences from which the digital alone is a bereft substitute.

Designing mixed reality applications and interior design layouts with a holistic design philosophy that balances the virtual and physical presents an opportunity to begin addressing these burgeoning issues. Digital programs can be designed that compel the user to use varying ranges of body motion to manipulate the augmented reality 3D user interface with the attendant benefits of getting exercise during the day while at work. The converse could also be applied for people with disabilities or limited mobility. Created balanced mixed reality compositions would benefit social interactions because the nature of an interior augmented reality system encourages the user to interface with the physical and explore or move around the environment to interact with the digital. Other people along with inanimate physical features inhabit this environmental mixed reality space so this would aid in shift the concentration of focus to social/interpersonal communications as well. To dovetail this notion, at the systems level of control in the settings, the user can control the gradient threshold of media assets in a region or go with prescribed defaults to modulate and balance out the digital in their space to suit their preferences.

5.2.2 Product Design Ideas + Improvement Suggestions

5.2.2.1 Input + Output Technologies

<u>Occlusion/Registration Error Solutions</u>

Object occlusion errors is one of the most prominent issues with optical see-through head worn displays among some other augmented reality outputs. These types of errors occur when a physical object either moves in front or behind a virtual object and the system is unable to display correctly it's orientation in space in addition to keeping the digital asset in correct registration with the environment. Recently, engineers have developed a technology called Simultaneous Localization and Mapping (SLAM) originally used to map environments for robotics which is now in the purview of augmented reality software developers. Most pointedly, designers are now including SLAM cameras and sensors in some present and future smart devices to solve the occlusion/registration errors. SlidAR a 3d positioning system developed for handheld augmented reality devices is one example of this in addition to a gaming experience called Ball Invasion that showcases realistic virtual occlusion and collisions with physical objects. [9]

This technology enables apps to generate more realistic interactions with the physical environment. This would be one solution for this issue and is certainly useful if the user is transiting between varied environments indoors and outdoors that might not necessarily be optimized for mixed reality in the sense that the processing system already having a map of the environment. However, another variation to solving this would be to embed these types of sensors in environments and interior design arrangements so that there would already be a virtual map data for the system to use from every angle. This modality of positioning sensor in the interior space is what is know as outside-in tracking. Whereas sensors placed on user worn devices is inside-out tracking

The system I proposed in chapters three and four of placing several depth + rgb sensors cameras within a mixed reality interior to overlay the environment with a selectively visible grid for digital asset placement could also be used to potentially eliminate occlusion errors. It could do this by providing the system with real-time updates of changes of the rotation, position, and translation of physical objects in space by scanning the interior and generating 3d constructions. In turn, this would feed that spatial input of the constantly updating 3D environment and any modifications back into the rendering system of the augmented reality display program and display peripherals eliminating any occlusion/registration errors at the source. Presently, it seems that outside-in tracking is mainly relegated to VR application, but I think it would be beneficial to consider their use in Augmented reality as well in tandem with user-worn displays. With this setup, the system is in reciprocal communication with the physical environment and not simply projecting onto it and giving developers the option to channel 3D spatial input data towards desired processes.

Ideally, if mixed reality applications could utilize map and positioning sensor data from both SLAM user-worn and environmental sensor cameras an optimal solution would have been achieved.

Holographic Arbitrary Surface Displays

Holographic or volumetric displays would be the ideal display medium for incorporating 3D user interfaces into an environmental space because they display the digital assets in actual physical spaces visible to the naked eye. However, most of these display types are currently limited to small device enclosures with the technology yet to be developed to have them exist within the entire interior setting of a building environment.

In the idealized scenario, these hybrid environments would utilize an arbitrary surface displays that would be holographic in nature. Arbitrary surface displays are another name for projection mapping in which clips of video or animation are projected onto a range of environmental surfaces both on interiors and exteriors with single or multiple projectors from varying angles. Adding a holographic component to these displays would render these

2d projections into virtual 3D objects providing that the media is three-dimensional in its native context. This type of holographic arbitrary surface display does not yet exist; however, it would be ideal in a mixed reality environment so that users could experience a more immediate immersive experience without having to wear special glasses or utilize other peripherals to see digital objects along with having to deal with the device's field of view limitations.

Multimodal Sensor/Pointer Ring + Grasping/Gesture based Methodology Explorations

Within augmented reality 3D user interface selection and manipulation modalities, the occlusion problems exist as well when it comes to users being able to accurately select and place objects that are at varying levels of depth that may or may not be in front or back of other digital assets.

After surveying many 3D input modalities each with their corresponding set of strengths, the idea of creating a system for selection that eliminates the occlusion issue utilizing minimalist peripherals that embodied some of these salient selection and manipulation techniques came to mind. More specifically, I am proposing the usage of an adaptation of the sensor ring and a possible smart/sensor bracelet or wrist band to enable bimanual selection abilities using gesture, tapping and pointing actions.

Traditionally, the sensor ring comes with 6 degrees of freedom sensors for gesture-based interactions along with physical buttons, but it would be interesting to see it with the added ray-casting functionality.

Ray casting is a simplistic virtual environment selection technique whereby an infinitely long ray is projected out of a user's handheld pointer device. This type of ray-casting has been attributed to selection errors because it can have a hard time differentiating behind foreground and background objects. The selection methodology using a combination of the mentioned input devices I'm suggesting below is a potential solution for this issue.

1. Sensor ring finger pointing determines spatial orientation vector of the ray cast. Even though the ray is infinite, it will only select the non-occluded visible digital assets in the foreground. A highlight will appear around potential selections when in the line of sight of the ray
2. Sensor ring finger thumb tap on one of physical buttons of the ring while ray is pointed on object will cause the item to be selected with a subsequent 3D manipulator widget activating to allow the user to change the rotation, scale or position in addition to a link to the main menu that would allow for deletion and more default interaction options
3. Double tapping on the same physical button of the ring accompanied by a hand grasping motion would activate a context sensitive volume soft selection tool whose radius is controlled by the up and down movements of the opposing arm/hand with the sensor wrist band equipped. This option is the well know cone-based selection technique but with more options as far as the shape of the selection volume goes. Having the ability to select multiple objects with a single movement is an important ability for efficiency in making selections in 3D UIs.

4. Once an item is selected, an additional tap on one of the selection buttons along with a gestural pass of the opposing hand over the sensor ring hand activates what I term as the null containment field. Like the soft selection technique above, this manipulation modality contains the same functionality yet instead of selecting the objects, this soft selection temporarily nulls the user's ability to select the objects in its radius by either making them invisible to transforming them into a semi-transparent wireframe. This technique would allow the user to access digital objects that have been occluded by foreground virtual assets thus presenting another possible solution to the occlusion issue.
5. A finger dance with the sensor ring hand will clear all selections

In this step by step process, a rough outline of a possible solution has been presented for AR selection problems using the infinite ray casting technique by utilizing combined methodologies of pointing, grasping and selection techniques in addition to usage of soft select functions to either select or null multiple objects. This technique of multiple selection and manipulation metaphors allows for the efficient selection of digital assets in either the foreground or background regardless of whether they are orientated in front of or behind other objects at any point in space.

Passive Haptic Feedback Homewares + Furniture + Soft goods

Passive haptic feedback devices are a form of both input and output or display and manipulation technology. They are displays because the physical object is an exact duplicate of a virtual representation and they are user interface controllers because they can be interacted with physically to cause changes in the digital environment.

Product designers could start considering the generation of wares that one would find in every day environments for mixed reality interiors with sensors or passive haptic feedback functionality. Interactions with an environmental augmented reality 3D user interface should be as natural as possible and the more avenues that allow users to accomplish a certain task affords the individual with a greater sense of variety and immersion.

I would suggest an extension of the passive haptic feedback definition to also include objects that don't necessarily have a digital twin. For example, if a product designer were to create a passive haptic feedback lamp for the interior it would not make sense for it to correspond necessary to an exact digital counterpart located somewhere in virtual space. However, it's related metaphorical digital functionality could be that it controls the overall lighting, colors and display resolution of the 3D UI along with being tethered to the global controls for the physical room's brightness and the functionality of any other lights in the space.

An example of passive haptic feedback soft goods functionality would be any items made with textiles in an environment that users encounter frequently. This could include quilts, blankets or wall-hangings or poufs with embedded sensors that would enable the user to access certain UI functions. An individual's comforter could turn into an augmented reality virtual/physical keyboard or it could serve to house quick access to their favorite reading materials or other varied digital media elements.

A lot of research, development and experimentation is necessary in this vein operating with the core aim that the environment is the AR computer interface with the blurring of the lines between the visible system's response to form, décor and function.

5.1.1 Mixed Reality Interior Design + Environmental Psychology Possibilities

Designers are encouraged to iterate upon the presented mixed reality methodologies and development models along with delving into certain aspects of the hybrid environment with greater specificity. For example, in chapter four Implementation, the simulated mixed reality environment concept was comprised of varying zones each with their own interaction goals while also being interrelated to each other and the whole space. The idea for the interior was to showcase how 3D user interfaces can be utilized in a dedicated environmental space to engage with multiple learning styles in an interactive sense rather than just through a single avenue.

The circulation zone or walk way which I termed as the zone of kinesthetics, allowed users to engage in exercise related functions along with quick status updates. The media gradient of executed apps in this zone were purposely kept simplistic bold with readily available icons and functions related to the purpose of the setting visible. In this case, researchers, designers and developers alike could delve into the nuance of the types of augmented reality programing that could be offered and how the physical space is constructed or further iterate upon the UI functional and graphical aesthetics. This could include research into the colors, patterns, sounds, shapes and forms that would encourage a sense of physical activity, energy and motion and overall user immersion into the functional purpose of this zone.

Included within this is the consideration about the role that biomorphic geometry and fractal form features in the interior environment play in generating emotional responses. It's a well-researched phenomenon in the vein of environmental psychology that restorative environments or spaces that provide for a sense of well-being and recovery from fatigue or stressors have a low to mid-range fractal dimension. This would be a fruitful avenue of research to pinpoint which types of fractal design elements evoke emotional responses beyond simply the general instorative effects for general patterns of intermediate complexity. What geometric properties encourage movement, as opposed to those of creative thought, or relaxed social interactions. When speaking of patterns, for a mixed reality setting this extends into how the physical as well as the virtual space and user interface is constructed.

Going back to our above example about the circulation zone, designers may want to encourage users to be physically active as opposed to resting here because the space is about motion. What specific geometric forms or fractal dimensions of complexity dovetail this aim? The development of a biomorphic design pattern language for emotional responses or instorative effects would be a helpful tool for mixed reality designers to craft effective and purposeful digital/physical mixed reality user interfaces for interiors.

6. CONCLUSIONS

6.1 Summation of Results

The design research journey of constructing 3D user interfaces within the context of mixed reality interiors has been investigated throughout the course of this document. Mixed Reality interiors in this case has been defined as an interior that is residential, public access or commercial that is specifically designed for being imbedded with augmented reality digital media content which could be considered akin to any other physical decorative/functional feature situated in an environment.

Presently, most augmented reality applications ensure that the media is in correct registration with physical surroundings where necessary and that location specific information can be accessed but little to no consideration has been given to how this digital media integrates into the design composition of the totality of an interior setting. The virtual elements must inform the design of the physical world and this relationship is reciprocal. The following sentiments by C. Alexander most aptly illustrates this point.

> "This is a fundamental view of the world. It says that when you build a thing you cannot merely build that thing in isolation, but must repair the world around it, and within it, so that the larger world at that one place becomes more coherent, and more whole; and the thing which you make takes its place in the web of nature, as you make it." [11]

With the advent of increasing advances in user worn input/output and display and systems manipulation technology, augmented reality media will become a habitual occurrence in our interior settings. Bearing this in mind it's important to start asking the critical questions of how designers can move away from these one-off types of applications into designing integrative systems that interrogate the whole environment by opening responsive exchange between the digital as well as the physical layers of a given setting. This provides a foundational structure to organize elements while composing balanced design compositions of a mixed reality interior. A system for organization is paramount to crafting user experiences with easily readable user interfaces and graphical interactive pattern languages that boast attendant cognitive benefits as some environmental psychologists would purport.

The pattern language for mixed reality interiors was developed by examining, historical precedents, journal articles, literature and case studies of relevant architectural interior, digital media and augmented reality systems along with correlating interior and media design principles couched within fractal archetypes and design philosophy. The questions about the how and why certain locations or spatial features are optimal for certain media assets existing in a spectrum of gradients with varying levels of modulated expression has been addressed. Different types of input/output modalities have been suggested for usage along with the identification of the core features and organizational templates a default mixed reality user interface might want to have in addition to suggestions for other types of functions based on thematic and spatial strategy context.

In chapter four implementation, these Mixed Reality Interior pattern language concepts were illustrated graphically in a 3D simulated environment that provided users with a visual cue of just one of the many possibilities to iterate upon during this multidisciplinary design process.

Finally, a Mixed Reality design pattern evaluation was presented along with considerations for further development into more nuanced aspects of the design process. These were discovered through the course of this design research process and shared in chapter five, evaluation.

The scope of this project was to explore new augmented reality territory through perceptions of correlating elements on the archetypal level of the interdisciplinary design process between digital media and interior design disciplines. This is aimed at encouraging a holistic strategy for conceptual development. Designers are encouraged to delve into finer granularities through user testing, further research and development of varying mixed reality prototypes utilizing these foundational elements a starting point in their quest to produce optimal augmented reality interior user interfaces and interaction modalities.

In the future, such mixed reality user interface templates will be created and installed in residential, commercial and even public access interior settings just as we presently install operating systems or applications on a traditional computer system or smart device. As advances in technology and human society continue to march forward, it will become increasingly relevant to consider the totality of the environment as the computer interface and it is high time to consider the multidisciplinary design components that work together to craft these virtual/physical environments of the future.

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