CREATING A VIRTUAL MUSEUM FRAMEWORK FOR IMMERSIVE REALITY ENVIRONMENTS THROUGH A PERSPECTIVE FROM HETEROTOPIA

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ABSTRACT

CREATING A VIRTUAL MUSEUM FRAMEWORK FOR IMMERSIVE REALITY ENVIRONMENTS THROUGH A PERSPECTIVE FROM HETEROTOPIA

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Extended realities introduced distinctive operations and concepts such as embodiment and collocation, which can change the way architectural places are produced. The heterotopia concept defines "worlds within worlds" which is a juxtaposition of unique elements, creating novel layers, relations, and meanings. This myriad approach can be extended to provide spatial relations for several activities, which can be altered through embodiment. In this thesis, based on the heterotopia concept, a virtual museum framework for Virtual Reality, Mixed Reality, and personal computer environments to provide a multi-layered experience for users from various backgrounds was created. The framework provides a platform where users can perform archiving, curating, displaying, and designing practices. Users can create individual virtual museums as discursive datascapes by being able to store data in different formats and transform and analyze their content. Through various procedural content generation algorithms, the developed platform allows automation for architectural design processes as well as for archiving and exhibiting. This thesis presents a comparative evaluation of the framework in terms of usability, technology acceptance, and presence based on the results of the user study, where the versions of the framework were tested by 30 participants. The outcomes of the study are discussed both through the heterotopia concept and the analyses of results that highlight the capacity of the developed framework to offer a much wider range of uses and the flexibility of being integrated into daily life practices.

Keywords: Virtual Museums, Virtual Reality, Mixed Reality, Procedural Generation, Heterotopia.

ÖZ

SARMALAYAN GERÇEKLİK ORTAMLARI İÇİN HETEROTOPYA PERSPEKTİFİYLE SANAL MÜZE ÇERÇEVESİ GELİŞTİRİLMESİ

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Genişletilmiş gerçeklikler, bedenleşme ve ortak yerleşim gibi mimari mekanların üretilme biçimini değiştirebilecek farklı işlemler ve kavramlar ortaya çıkarmıştır. Heterotopya kavramı, yeni katmanlar, ilişkiler ve anlamlar yaratan benzersiz unsurların bir araya gelmesi ile oluşan "dünyalar içinde dünyalar"ı tanımlamaktadır. Bu sayısız yaklaşım, bedenleşme yoluyla değiştirilebilen çeşitli faaliyetler için uzamsal ilişkiler sağlamak üzere genişletilebilir. Bu tezde, heterotopya konseptini temel alarak, farklı geçmiş deneyimlere sahip kullanıcılara çok katmanlı bir deneyim sağlamak için Sanal Gerçeklik, Karma Gerçeklik ve kişisel bilgisayar ortamları için bir sanal müze çerçevesi oluşturulmuştur. Çerçeve, kullanıcıların arşivleme, küratörlük, sergileme ve tasarım pratiklerini gerçekleştirebileceği bir platform sağlamaktadır. Kullanıcılar, farklı formatlardaki verileri depolayarak ve kişisel içeriklerini dönüştürerek ve analiz ederek gidimli veri ortamı formasyonları olarak tanımlanabilen bireysel sanal müzeler oluşturabilmektedirler. Geliştirilen platform, çeşitli prosedürel içerik oluşturma algoritmaları aracılığıyla, mimari tasarım süreçlerinin yanı sıra arşivleme ve sergileme için otomasyon sağlamaktadır. Bu tez, çerçeve versiyonlarının 30 katılımcı tarafından test edildiği kullanıcı çalışmasının sonuçlarına dayalı olarak, kullanılabilirlik, teknoloji kabulü ve bulunuşluk açısından çerçevenin karşılaştırmalı bir değerlendirmesini sunmaktadır. Çalışmanın çıktıları hem heterotopya kavramı üzerinden hem de geliştirilen çerçevenin çok daha geniş bir kullanım sunma kapasitesini ve günlük yaşam pratiklerine entegre edilebilme esnekliğini vurgulayan sonuçların analizleriyle tartışılmaktadır.

Anahtar Sözcükler: Sanal Müze, Sanal Gerçeklik, Karma Gerçeklik, Prosedürel İçerik Üretimi, Heterotopya.

To my family

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
BIM	Building Information Modelling
CAD	Computer-Aided Design
CAVE	Cave Automatic Virtual Environment
EUD	End-User Development
HCI	Human-Computer Interaction
HMD	Head-Mounted Display
ICOM	International Council of Museums
IE	Immersive Environment
ISO	International Standards Organization
METU	Middle East Technical University
MR	Mixed Reality
OOP	Object-oriented Programming
PQ	Presence Questionnaire
ST. D.	Standard Deviation
SUS	System Usability Scale
TAM	Technology Acceptance Model
UI	User Interface
UX	User Experience
VPL	Virtual Programming Languages
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

1.1. Problem Statement and Motivation

The 20th century has been a period of significant reevaluation and reconceptualization in various disciplines as they moved away from traditional foundations. This process of breaking away from the past and embracing change was accompanied by destructive and creative events that had a lasting impact on discursive practices [1]. The construction and dispersion of knowledge are unique to each culture, field, and individual and are achieved through inclusion and exclusion. The included elements are then interpreted and narrated to give meaning and produce knowledge [2]. The medium and manner of discursive practices have changed within the digital cultures shaped by digitalization and digitization processes. Technology has allowed actors to operate on the vast array of multimedia information, defined as the "formless chaos of knowledge," to organize, produce, consume, and preserve it [3]. As personal computers and mobile phones become increasingly prevalent in society, they have started to alter or even erase the particular layers that provide individuals with a sense of place and identity, which have created phenomena referred to as "placelessness" and "formlessness" by Odom et al. [4]. Spatial layers have become less of a focus, and the digital realm has become more prominent. This has caused individuals to rely on virtual possessions in the digital sphere to find a sense of belonging and connection, eliminating embodied cognition [5].

The disappearing layers in digital societies can re-emerge with recourse to Foucault's heterotopias, "areas of resistance that intensify knowledge" [6]. According to Michel Foucault [7], heterotopia is a space standing outside of its known place, a space of otherness, remaining simultaneously separate from and connected to other spaces. Foucault identifies several strategies for constructing discourses within this space, including the "operating table," "surfaces of emergence," "authorities of delimitation," and "grids of specification" [8]. These strategies can be utilized in various ways within the context of heterotopias. Considering the connection between place, embodiment, and multimedia, being heterotopias "virtual museums" can facilitate various discursive practices presenting individual archives on an "operating table" by incorporating virtual reality (VR) and mixed reality (MR) technologies. In this research, the term "virtual museum" refers to a vast, multifaceted realm that encompasses a wide range of entities that both exist in physical locations and are depicted through media. The exhibitions contained by museum space create a rich, layered narrative that provides a "world within worlds" through the creation of immersive, digital places. This way a complex system of understanding can be created that allows for the development of new approaches providing embodied cognition.

1.2. Purpose of This Study

In this study, through the lens of Foucault's concept of heterotopias, we aimed to provide a digital realm created through the flow of data from individual archives and shaped by immersive technologies to offer the production of a multi-layered discursive space providing various levels of reality. Through extensive literature research, we identified the gaps in several areas and the requirements for creating discursive space in immersive environments.

The way archives are created and kept has changed due to the continuous evolution of technology in the expanding digital world. The COVID-19 pandemic has further emphasized our reliance on technology and revealed new facets of its use and the molding process of technological systems that have been altering the content and built environment to which we are exposed. However, the wide variety of data types, including texts, videos, 3D models, images, and audio files, that are accessible through different software or interfaces can make it difficult for end-users to store, display, and interact with all this information in the same space, potentially hindering the comprehensive acquisition and production of knowledge. Additionally, they are incapable of providing 3D interaction due to the technological medium. While personal computers and mobile devices are commonly used to store individual archives, newer technologies, such as virtual and mixed realities, have provided new avenues for accessing information. Through embodiment, mixed and virtual reality technologies have the potential to create a spatial layer of heterotopias by creating immersive, interactive digital environments that can mimic the feeling of being in a physical place or blend the physical space with the virtual and provide a sense of place and connection to their surroundings [9].

There are significant studies that provide seamless interaction between BIM and CAD tools in immersive environments, which have a powerful impact on the areas of construction management [10], [11], architecture [12], [13], and cultural heritage [14], [15], providing efficiency and new dimensions. However, the complexity of tools and techniques utilized by practitioners in specific fields may pose difficulties for novice users. While these studies demonstrate the presence of spatial layers, they have been created with a particular discipline in mind. Thus, they are not inclusive in terms of multimedia and only offer discursive practices for the intended field, precluding their application in other contexts.

Foucault [6] describes museums as heterotopias, but not all museums necessarily function as discursive heterotopias. The current applications show that large corpora consisting of virtual museums provide abstract or exact copies of a real museum with isolated interactions based on predefined paths [14], [16]. There is an increase in the number of studies improved by individualization being incorporated in a static, designed, built environment [17], [18]. Virtual museum applications offer a wide range of multimedia elements; however, they provide static functions, and personal content has been limited to images. A system that possesses the technical capability to integrate a plethora of personal media, such as text, audio, and 3D graphics is not available. Digital “emplacements” in virtual museum and cultural heritage studies fail to facilitate the rearrangement and inclusion of comprehensive individual content. thereby lacking the adaptability necessary to accommodate the idiosyncrasies of the user. Therefore, these technologies are usually unable to provide the “operating table” functions and enough autonomy to users which produces the resistance of heterotopias [19].

The integration of automated tools can facilitate the design process and enable users to create more complex and accurate designs in terms of function and dimension. The level of autonomy of a tool can also have an impact on architectural design practices [20]. Tools with high levels of autonomy may require less input from the user, but they may also limit flexibility and creativity. For a co-creation process, the comprehensibility of an automation system is necessary to produce consistent and functional designs. While algorithms have been successful in providing a diverse selection of options in the gaming industry [21], [22], they do not offer the same level of customization in other industries and may not cater to the needs of all users. By adopting the PCG approach and incorporating customization options, it may be feasible to design a virtual museum that accommodates users of varying expertise.

Resistance is a fundamental aspect of heterotopias, which emerge from the adaptability and shifts in functions due to dynamic power dynamics. The individual is seen as a driving force in modernity, a “focal point of resistance” able to shape and influence their experiences together with their surroundings [23]. By working in tandem with the systems they are a part of, they become “authorities of delimitation” [2]. Therefore, the framework aims to be a modular and dynamic structure utilizing object-oriented programming. Being open to manipulation to change functions according to user needs gives the ability to import various media formats providing automation to transform the elements into interactable artifacts to empower individuals to become “authorities of delimitation” where they construct digital habitats in immersive settings.

Discursive spaces are environments where discourse takes place, and knowledge is produced through the examination of different perspectives. These spaces offer opportunities for individuals to engage with various forms of information, encourage the development of critical thinking skills, and facilitate the creation of new knowledge [24]. Heterotopias are discursive spaces that can juxtapose elements received from “surfaces of emergence” and reveal hidden relationships, making them particularly useful for enabling knowledge production. The framework aims to serve as a platform that allows users to manipulate and interact with various elements of multimedia language in customizable environments, expanding the space of heterotopias. It acts as an “operating table” in this sense.

Heterotopias have a unique relationship to both time and space; they exist outside of linear, chronological time, often serving as a reflection or representation of ideas. Spatial layers become ordering mechanisms in heterotopias through their function as spaces of separation, inclusion, and exclusion [6]. Places function as “grids of specification” by imposing a particular set of rules and norms to reorganize the content. To increase the autonomy of the user, the framework offers “liquid architectures" that can be formed directly by individuals or according to their needs to provide the "order of discourse" [25]. Together with various architectural elements that can be used to build spatial layers, it offers procedural generation algorithms (PCG) with different levels of autonomy. As a result, with the places and the complex relationships they hold, another layer emerges [26].

The virtual museum concept was selected for this study due to its ability to encompass a range of entities offering both architectural design practices and media representation and reproduction, serving as a space for transformation for diverse disciplines. A virtual museum's design may be considered a continuous process that begins with documentation and advances via the application of creativity and experience gained inside the virtual space. By incorporating virtual reality and mixed reality technologies into the design process through the construction of heterotopias with various levels of reality, a complex system of information can be developed that enables the creation of new ways to produce knowledge and places.

Based on these findings, the objectives of our research are as follows:

- To systematically review and analyze previous studies that provide theoretically grounded design principles for developing an inclusive framework, considering the diverse information they incorporate.
- To devise an automated framework for VR, MR, and PC environments that can be utilized for diverse disciplines to create heterotopias where discourse can occur.
- To provide embodied place-production activities for professionals and non-professionals.
- To produce techniques that can present various autonomy levels and are capable of producing "liquid architectures" that can provide design space for the users.
- To assess our proposed framework's usability, acceptance, and provided presence levels and compare various technologies to gain more insights.
- To identify the various elements of place production and media formats that can influence user experiences and preferences.
- To deduce design features and results that can inform future work in the Human-Computer Interaction (HCI) community.

1.3. Research Questions

It is essential to understand how people perceive and make use of technology and the factors that shape and restrict the development of technological tools in our technology-driven society. Meta-design and end-user development (EUD) [27] can facilitate the more widespread adoption of immersive technologies by allowing users to actively participate in the design process and tailor the technology to their specific needs and contexts. This can create a more comprehensive and holistic dialogue between the system, user, content, and place, ultimately leading to greater integration of these technologies into daily life. In addition to their potential for enhancing architectural discourse, immersive technologies can provide embodied cognition in a variety of contexts, allowing users to cognitively engage with and experience a place as if they were physically present. However, despite their potential to offer rich, multi-dimensional interfaces, virtual and mixed-reality technologies have yet to be fully integrated into daily professional and personal lives [28]. Therefore, this study aims to identify design features that can enhance the integration of immersive technologies into diverse contexts through the development of new approaches by addressing the following questions:

Deriving from our objectives and observations, this study aims to provide answers to the following questions:

- R1. In terms of usability, presence, and technology acceptance which technology can provide better user experiences, and what are the causes of differences?
- R2. Which digital environment is more suitable for interaction with varying media formats?
- R3. How are the different technologies and embodiment affecting the construction process of virtual environments?
- R4. How do features of the digital space affect users' experiences and their curation, modeling, and visitation processes?
- R5. To what extent are the number and types of options presented to manipulate design outcomes that can create a sense of control over the algorithm, and how does the autonomy level of procedural generation algorithms affect users' preferences and design outcomes?
- R6. How does the experience level affect technology acceptance, usability, and presence results?

1.4. The Contributions

Within the context of this study, we created a versatile framework based on the features of discursive heterotopias. The developed framework can be employed by a wide range of disciplines and audiences, which gives the ability to facilitate further research and diverse contexts. The framework offers virtual museums as a playground for archival practices where the context is defined by the user creating a "world within worlds." The spatial layer of heterotopias provided by several architectural elements serves as building blocks and different options for texture, lighting, and scale preferences. Additionally, we provided three PCG algorithms to support architectural and archival practices; Binary Space Partitioning (BSP) blended with Cellular Automata (CA), procedural room generation, and constraint growth algorithm. Different from the previous studies, we provided several autonomy levels to users by injecting user preferences and data-based techniques. The provided techniques offer "liquid architectures," which are formed by the users. Through the spatial layers, the architectural elements offer "grids of specification" and present place production as a subject of discourse. The framework allows import operations for 3D model, image, audio, video, and text formats and provides automation for transforming the assets into interactable artifacts in immersive environments where individuals become "authorities of delimitation." Archival processes are supported via various algorithms enabling the grouping and examination of individual content. In the design process, we adhered to meta-design and end-user development (EUD) principles in order to develop a flexible and modular framework that could be adapted to the needs of users in various contexts. This approach allowed us to create a system that could be molded to meet the diverse requirements of different users, facilitate self-formation practices, and provide individuals to become “focal points of resistance.”

This research endeavors to understand the impact of various technologies on the user experience. Therefore, we developed different versions of the framework for three platforms: PC, VR, and MR. To test the various aspects of the developed framework and to provide insights that can increase the pervasiveness of immersive technologies, we conducted a comparative study involving 30 participants. Following exposure to the system, participants completed standardized assessments of presence, technology acceptance, usability, and system-specific surveys. Additionally, we conducted semi-structured interviews to more deeply understand the objective and subjective data collected through these measures. Findings reveal that the framework successfully delivers consistent levels of usability and acceptance across technologies, and the multi-layer approach provided via heterotopias is well-suited for diverse contexts.

This study not only serves as a tool for constructing discourse for individual practices but also makes a significant contribution to various academic fields, such as virtual museums, archival practices, immersive technologies, architecture, history, archaeology, digital humanities, and media studies. The proposed framework, which facilitates research in diverse contexts and supports archival processes, as well as enables the import and automation of various forms of media, holds significant potential for these fields. The concept of discursive heterotopias, and its integration into the framework, presents a valuable perspective for architectural and urban studies. Furthermore, the study’s examination of the impact of various technologies on the user experience can provide valuable insights for researchers in fields such as human-computer interaction and user experience design.

The results and insights produced through the following studies prepared the ground for the framework presented;

- Korkut, E. H., & Surer, E. (2023). Visualization in virtual reality: a systematic review. Virtual Reality, 1-34.

- Korkut, E. H., & Surer, E. (2021, November). Sketch Recognition for Interactive Game Experiences Using Neural Networks. In International Conference on Entertainment Computing (pp. 393-401). Springer, Cham.

Additionally, this study (Heterotopias as Discursive Playgrounds) made it possible to produce a research article that was submitted to a journal indexed in the SCI-Expanded and uploaded as a preprint to arXiv.org.

- Korkut, E. H., & Surer, E. (2023). Developing a Framework for Heterotopias as Discursive Playgrounds: A Comparative Analysis of Non-Immersive and Immersive Technologies. arXiv preprint arXiv:2301.08565.

1.5. The Organization of the Thesis

This thesis is composed of 7 chapters organized as follows:

- Chapter 1 explains the problem statement and motivation, the purpose of this study, the research questions, and the contributions of this thesis.
- Chapter 2 presents a literature review that describes previous work on discourse, heterotopias, and virtual museums, explains the historical development of VR and MR technologies and related concepts, summarizes discussions on architectural production, introduces various types of PCG algorithms in the literature, and reviews previous work on virtual museums and heterotopias.
- Chapter 3 presents the design rationale and details of the developed framework.
- Chapter 4 describes the evaluation methodologies.
- Chapter 5 demonstrates the results.
- Chapter 6 discusses the results with the concepts provided in the literature review.
- Chapter 7 summarizes the study and explains future work and limitations.

CHAPTER 2

LITERATURE REVIEW

2.1. Discourse and Heterotopias

Michel Foucault was a French philosopher who studied the ways in which power and knowledge are interconnected and how they shape society. He identifies certain places, called heterotopias, that not only represent and reflect the relationships between different parts of society but also challenge or contradict them [7]. Heterotopias are real places that exist within a culture and function as a sort of "realized utopia" where other places within the culture are reflected upon, challenged, and inverted. The term heterotopia originally came from the study of anatomy, which refers to a part of the body that is alien or foreign. Michel Foucault further developed the concept in his book "The Order of Things" and in an essay called "Of Other Spaces," in which he defines heterotopias as sites that allow the ordering of things inside it not through resemblance but rather through the process of similitude [6][8]. Heterotopias are unique spaces that have the ability to bring together and contrast various spaces and concepts within a culture. They can manifest in various architectural forms, functions, and sizes and serve as a means of reflecting and challenging the relationships between different parts of society. Heterotopias serve as a means of examining and questioning the values and norms of a culture, offering a glimpse into alternative ways of organizing and understanding the world.

In his analysis of power and knowledge, Michel Foucault argued that discourse plays a central role in shaping our understanding of the world [29]. Discourse refers to systems of thought and ways of discussing and representing the world. Discourse includes compositions used to make sense of the world and communicate with others. The discursive space is a representation of knowledge that arises from the world of findings via the accumulation of specialized knowledge about it. As a result, it is not a standalone system but connected to other systems through the circulation of information [30]. According to Foucault [23], there is a need for several strategies to construct discourses: "operating table," "surfaces of emergence," "authorities of delimitation," and "grids of specification."

The operating table symbolizes the space where knowledge is formed and serves as a tool for organizing and understanding different objects. It is a foundational space where objects are placed together to create meaning and shape our understanding of the world. A surface of emergence is the edge of an existing discourse that allows related discourses to grow from it [2]. For example, the discourse of environmental science emerged from the surfaces of geology and biology, and the discourse of fashion emerged from the surface of art and culture. These surfaces provide the foundation for the development of new discourses and the creation of new subjects. An authority of delimitation defines a set of rules that identifies the manner in which a discourse can identify objects that can become subjects within that discourse. A grid of specification is a systematic taxonomy of concepts used to place objects in an ordered hierarchy or table so that they can be identified as types of subjects within the discourse. For example, in the discourse of biology, the classification system developed by Linnaeus is a grid of specifications that orders living things into categories such as phylum, class, order, family, genus, and species. This lets biologists identify and categorize living things based on their features and put them in the right group. By understanding the role of these theoretical strategies in creating subjects from objects, he explains how discourses shape our understanding of the world and the ways in which we act within it [31].

Heterotopias are distinctive epistemic contexts that can facilitate discourse. In Of Other Spaces, Foucault identifies six critical features of heterotopias and provides several examples to illustrate these characteristics. According to Foucault, although it can take quite various forms, every culture produces heterotopias. He divides those heterotopias into two: deviation and crisis. He exemplifies these heterotopias with boarding schools and prisons. Heterotopias often function as sites of social and cultural critique, offering an alternative vision of the world and a place for people to experiment with different ways of living. Heterotopias can serve different purposes within a society, depending on the culture and time. The function of a heterotopia is specific and established within a society, but it can change over time as the individuals change.

In the works of Michel Foucault, "resistance" refers to actions or behaviors that challenge or oppose dominant power structures. Foucault argued that resistance is not something that exists outside of power relationships but rather is an intrinsic part of power dynamics. According to Foucault, power is not a static entity; instead, it is constantly negotiated and contested through interactions. Through these negotiations, heterotopias change their functions [31].

Heterotopias are capable of juxtaposing several spaces that are incompatible in a single real place. By juxtaposing and combining many spaces in one site, heterotopias problematize received knowledge. Foucault also studied the role of archives in shaping knowledge, arguing that they not only preserve historical documents but also play a role in constructing and organizing knowledge. Foucault believed that the rules, systems, and procedures that govern our understanding and pursuit of knowledge, or what he referred to as the "order of discourse" [8]. These discursive practices, which include the selection, organization, and redistribution of discourse, both inhibit and facilitate knowledge production and involve a balance of exclusions and choices. By providing different syntaxes, heterotopias form discursive spaces. Foucault also emphasizes the importance of spatiality in his analysis of statements. Heterotopias in this sense, reorder knowledge based on partitions in places that provide "grids of specification." He presents the concept of the "operating table," where discourse occurs through exercises on relationships, interactions, inclusions, and exclusions.

Thus, as a feature of discursive heterotopias, the operating table represents the complex and dynamic interplay between power, knowledge, and discourse.

Heterotopias are places that are linked to slices of time. They can accumulate time indefinitely, such as archives and libraries, or provide temporal slices, such as exhibits or festivals. These spaces have the ability to collect and store all times, epochs, forms, and tastes in a single place that is outside of time and not subject to its changes. This concept is especially relevant in the modern era, when archives, libraries, and museums are being transformed into expressions of individual choice. The concept of "self-formation" that Foucault draws upon involves the idea that the relationships between different forces that act upon bodies, people, and practices of knowledge and living can be understood as a form of interiority [26]. The individual is also seen as a "focal point of resistance" that emerges as a result of power to shape their own products and together with the system used, they become "authorities of delimitation."

Heterotopias are spaces that have a system for controlling access and allowing entry, which separates them from other places and allows them to be entered. They are typically not freely accessible like public spaces. This can be seen in technological systems that use devices or personal accounts to control access.

The last characteristic of heterotopias is that they have a specific relationship with the rest of the space around them. In terms of discursiveness, this relationship forms "surfaces of emergence." This relationship can take two forms: either creating an illusionary space that reveals the nature of all other real spaces or creating a completely separate and orderly space in contrast to the messiness of the space around it. The function and spatial qualities of places shape the relations, meanings, and perceptions that can be perceived via embodiment.

2.2. Museum Topology and Museums as Heterotopias

One way to define a museum is through a conceptual approach, examining concepts such as heritage, institution, society, ethics, and museal. Additionally, it can be defined by theoretical and practical considerations, including museology and museography, as well as by its functions, including the preservation, research, communication, education, exhibition, mediation, management, and architecture that result from it. Furthermore, the museum can also be defined by its actors and the activities that ensue from it [32]. International Council of Museums (ICOM) defines a museum as "a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing" [33].

Museology is an interdisciplinary field of study that examines museums' spatial, architectural, and social aspects. It is a relatively new field that emerged in the late 20th century and draws on various disciplines, including architecture, urban planning, sociology, anthropology, and art history [34]. One of the key aspects of museum topology is the idea that the design of a museum should be responsive to the specific needs and goals of the institution and its visitors. Museology also considers the museum's role in the digital age, how the museum interacts and engages with the visitors through new technologies, how the visitors interact with the collections and exhibitions, and how to design the physical and digital spaces to provide a seamless and enjoyable experience [35].

Museums and archives have undergone significant changes throughout history. In the early days, museums and archives were often individual collections gathered by wealthy individuals. These collections were often private and not accessible to the general public. They were also typically focused on collecting and displaying art and artifacts from the past, with little emphasis on scientific or educational purposes. During the 18th and 19th centuries, museums shifted towards a more public and educational focus. The concept of the "universal museum" emerged, where institutions aimed to collect and display various objects and artifacts from different cultures and historical periods [36]. This period also saw the rise of the modern research museum, where collections were used for scientific study and research. In the 20th century, museums and archives continued to evolve and expand their focus. Many institutions began incorporating more interactive and educational exhibits and expanded their collections to include more contemporary and diverse materials. The 1960s and 1970s saw the rise of the "participatory museum," where visitors were actively encouraged to engage with the exhibits and collections. In recent years, with the advent of digital technology, many museums and archives have started to digitize their collections and make them available online [37]. This has allowed for greater accessibility and reach and new opportunities for research, education, and engagement. Digital museums and online archives have also allowed for new forms of curation, presentation, and interpretation of collections.

The museum phenomenon is rapidly developing, and it may be observed that the traditional concept of a museum as a single, unified institution with a specific discourse or way of presenting information has evolved into a more diverse and varied concept. Instead of a single institutional form, many different types of museums now employ a range of discursive practices or ways of communicating information and ideas. As a result, the idea of a "museum" has become more complex and nuanced, reflecting a changing understanding of the role of museums in society and the ways in which they can be used to convey information and ideas [36].

Michel Foucault's idea of the museum as a "heterotopia" suggests that museums should be viewed as spaces encouraging resistance. He argues that the museum, through his method of genealogy, can promote progress by juxtaposing objects from different times and encapsulating the entirety of time while also being insulated from the normal flow of time [6]. He emphasizes the spatial and temporal aspects of the museum, noting its ability to evoke a sense of both timelessness and a return to a past "natural" way of life. He identifies three key elements that make the museum a heterotopia: its combination of objects from different periods, its aspiration to present the entirety of time, and its isolation from the normal flow of time [38].

Foucault's idea of the museum as a heterotopia is a valuable perspective for understanding the function of museums as places of representation and distinction. He contends that the museum, as a product of the Enlightenment, continuously engages in self-evaluation and is open to the possibility of challenging its fundamental principles. This approach diverges from the conventional concept of seeking "universal structures." Instead, it embraces an examination of the historical events and societal influences that have shaped the museum's existence and public presentation. This understanding of the museum as heterotopia enables a more nuanced perspective on the museum, which is not limited by its historical context or display techniques but rather emphasizes its role as a space for challenging and contesting problematic concepts [29].

The discursive formation within a museum setting allows a plurality of interpretations to be gleaned from the objects on display. The curation and classification of the collection play a crucial role in creating a coherent narrative from disparate objects. The museum manages the physical display of artifacts and the informational layer through labeling. The labeling acts as a link between the physical manifestation of the object and its intangible informational content, thereby facilitating a deeper comprehension and interpretation of the object within the museum's context [39].

The architecture of museums is the art of designing and building spaces to house specific museum functions. The modern museum originated in the late 18th and early 19th centuries and has its specific architecture linked to the requirements of preserving, researching, and displaying collections. Major architectural changes in the 20th century, the increase in the number of temporary exhibitions, and the decentralization of some museum operations required the building or installation of specialized autonomous buildings [40]. Museums are becoming more aware of the physical location of their buildings and spaces and their place in the larger discourse. In today's world, new ways have been developed to address situations that traditional representation methods cannot handle. This has led to new forms of personal storytelling requiring different types of places, which can supplement or completely change traditional methods. Within the virtual museum settings architectural representation of a museum becomes both containers and contained [41].

2.3. Heterotopias and Virtual Playgrounds

"Place-making" is a term that refers to the practice of designing and shaping physical spaces. It originated in the 1960s, when architects, urban planners, and designers sought to improve the appearance of cities by revitalizing and modifying public spaces [42]. "The right to the city" is an idea that emphasizes individuals' rights to shape and influence the city in which they live and to participate in decisions that affect its development [26]. This concept, first introduced by French philosopher Henri Lefebvre in the 1960s, includes the right to access and use urban spaces, the right to housing, and the right to engage in the social, cultural, and political life of the city. The right to the city is not only political and economic but also a social and cultural one. In his later studies, he proposed a three-part understanding of space known as the "triadic combination," which consists of "conceived space," "perceived space," and "lived space" [43]. "Conceived space" refers to the physical and material characteristics of a place, such as its geography, infrastructure, and built environment. "Perceived space" is observed through the movement of people and objects within a place and can be measured through observation. “Lived space” involves the personal experiences and understandings of individuals within a place and can include the emotional, cultural, and symbolic meanings that are attached to it. According to Lefebvre, all three dimensions of space are interconnected and mutually constitutive, and the production and transformation of space are fundamental aspects of social life.

Drawing from the works of Lefebvre and Foucault, Soja [44] proposes another trilogy that also recognizes the interconnectedness of different types of space and the importance of considering the social and cultural dimensions of space. He explains Thirdspace as the social, cultural, and political spaces that exist beyond the binary of physical space (Firstspace) and mental space (Secondspace). However, his focus on the “representations of space” produced by media and social theory distinguishes his approach from those of Foucault and Lefebvre [45].

Marcos Novak believes that digital media has created a new virtual reality that is shaped by data and information in the form of electronic architecture. This digital territory allows for the exchange of images and information and should be experienced through the senses [46]. Novak’s concept of “liquid architectures” in cyberspace suggests a shift in how we think about the organization of information and the creation of responsive, multimedia environments. The term “worldmaking” refers to the process of creating these new realities through digital media. This virtual reality constitutes a new form of human experience that involves an alternative state of embodiment. One way to understand Novak’s approach is to consider how it incorporates nonlinear information and speculative philosophy into multimedia. This integration of different modes of presentation is an attempt to incorporate a diverse range of human experiences [25].

In his book “The Language of the Media,” Lev Manovich [47] defines new media as digital products that can be either entirely computer-generated or converted from analog sources. These products have key principles such as numerical expression, modularity, automation, interchangeability, and cultural transcoding. The modular nature of new media allows it to be made up of smaller media elements that can be assembled to create a larger product, while still retaining their individual existence. New media can be produced and modified through automation due to its digital coding and modular structure. It can also be presented in various forms and interpreted in the context of both human culture and computer ontology. Manovich suggests that the numerical expression and automation of new media permit procedural production and the potential for a reduced human role in the creative process. Juxtapositions of different elements have been provided via various tools. For example, PC-based second brain or note-taking applications offer text, image, audio, and video collation and use them as operating tables to construct discourse. However, they do not offer places, embodiment, or comprehensiveness in terms of multimedia, which eliminates the impact of scale and 3D relations. Spatial layers, place, and embodiment aspects of heterotopias have been provided via immersive technologies [48].

World-making activities have been provided by games for decades, where players can shape and influence the virtual spaces within the game [49]. These activities can range from building and constructing structures and landscapes to customizing and decorating the appearance of these spaces. For individuals, they provide an opportunity to express creativity and personalize their virtual spaces and foster a sense of ownership and attachment to the game world, as players feel a sense of pride and accomplishment in creating and shaping their own spaces. Boldi et al. [50] focus on the ways in which people have used video games to cope with and understand the impact of the crisis, particularly the COVID-19 pandemic. As people were forced to spend more time at home, some turned to video games as a way to escape their everyday routines and explore new virtual environments. Others used games to recreate or substitute for real-world places that were no longer accessible to them. The researchers propose that video games and online communities could be designed to allow users to customize virtual spaces and strengthen their attachment to them, potentially helping people find new purposes and opportunities in their daily lives.

Virtual museums and immersive cultural heritage studies can be understood as heterotopias of deviation and crisis. The potential for the loss of physical artifacts due to natural or man-made disasters has necessitated the reconstruction of these items in a digital format. Additionally, the COVID-19 pandemic has imposed barriers between individuals and places, leading to an acceleration in the use of virtual museums to provide access to cultural heritage. The "memory institutions", comprising galleries, libraries, archives, and museums, have transformed with the adoption of digital media and a focus on narratives, known as the "narrative turn." Utilizing technologies such as virtual and augmented reality, 360-degree photography, and 3D reconstructions, these institutions are able to transform and create places, increasing their presence in digital spaces, including websites [49].

By combining digital and physical places, Rousseaux and Thouvenin [19] investigated Informed Virtual Sites (IVS) through Michel Foucault's heterotopias. As a further development of Foucault's language, they also gave these diverse locations the term heterovirtopia. The method of loci often referred to as the mind palace, is a memory technique that enables people to recall information by connecting the object and subject associations with the location they are familiar with and the information they desire to remember. To properly recall information, this memory strategy primarily makes use of spatial memory. By fusing information with real-world locations in mixed reality, Yamada et al. [51] created a system called HoloMoL that uses the mind palace strategy to aid in user memory. This serves as one another example of informative topologies.

Malraux [52] demonstrates how placing works of art on exhibit in official museums ruins their distinctive traits and reduces their specific value. He suggested creating a "Museum without Walls" filled with images of artistic creations. A paradigm change in terms of contemporary senses inside the museum environment has been brought by mediated culture. Online platform initiatives like Google Art and WikiArt High-resolution images of selected artworks have been available to viewers worldwide. Modern online virtual museums and "Museum without Walls" diverge substantially, yet they both have the philosophical objective of transforming information and knowledge into forms that are accessible.

As a result of greater usage of new media technologies, the museum began to extend outside of physical locations, giving rise to the idea of the digital museum. The design of virtual museums is influenced by a wide range of elements, including media and digital resources. According to Schweibenz [53], the degree of accessibility is the key distinction between conventional physical museums and virtual museums.

To improve the experience of presence in a virtual world, immersion and interactivity in immersive environments are goals. This does not imply that every component of the environment is entirely fictitious [54]. Digital media may be created from physical artifacts by using 3D data collecting methods like photogrammetry and laser scanning. These methods are frequently used in a variety of industries, including cultural heritage, virtual museums, and virtual exploration [15], [55], [56]. Web scraping was used in Hayashi et al.'s [57] construction of a virtual museum that can exhibit planar objects. This was finished to obtain the necessary information. Users of the system can select the museum's material, which was authored by several authors. When historical interactive representations are combined with corresponding physical items and exhibitions, the use of MR technology in museums has the potential to improve the experience. The MuseumEye [58] application concentrates on various guide strategies to enhance visitor experiences. Komianos et al. [18] developed an automated virtual exhibition building based on adaptive display topologies to create flexible exhibition spaces. They claim that making navigation easier for visitors has the potential to improve users' visits.

2.4. Immersive Technologies

2.4.1. History Definitions and Taxonomies

The desires of artists, performers, and scientists to convey their ideas or productions blended with imagination based on experiences are preceded by the creation of artificial layers on top of real worlds and eventually to virtual reality. Illusionary spaces combining 2D images and 3D elements, such as monumental panoramas, have been created to give the impression of "being there" [59]. In 1939, based on studies of vision and depth perception, Fred Waller and Ralph Walker invented Vitarama, today is known as the Cinerama. Vitarama creates immersion and fulfills peripheral vision using cameras, projectors, and a curved screen [60]. Influenced by this technology, Morton Heilig developed systems called Telesphere Mask (1960) [61], the first notable instance of a head-mounted display (HMD), and Sensorama (1955) [62]. Sensorama was built to enhance cinematic experiences, including odors, vibrations, and visuals, inside a built-in seat with a semi-closed screen. Ivan Sutherland, a visionary scientist, and inventor, combined output devices that display visual representations with input devices that enable image manipulation in his creation, named Sketchpad [63]. With the concept of "ultimate display," he anticipated that technological advancements would eventually allow the creation of virtual experiences that could converge into real-life experiences [64]. He created a headset that offers a simulated three-dimensional environment to improve the efficacy and legitimacy of virtual worlds, proving that the realization of his vision is possible. The ideas and innovations of Scott Fisher [65] from 1987 suggest the possibilities of telepresence technology that converts virtual reality into an interactive and all-encompassing medium.

The HMD technology had several limitations since it was still in its inception phase. The CAVE (1993) [66] technology was suggested as a solution to these issues. It is a room-sized immersive 3D visualization system that enables multiple users to manipulate human-scale digital presentations. Although the notion and technology of virtual reality have existed for decades, the phrase was first used in 1987 by computer scientist Jaron Lanier as part of his extensive study on virtual programming languages (VPL) [67]. Essentially, VR can be described as a technology that employs stereoscopic vision or peripheral vision to simulate a real-world visual experience in entirely synthetic computer-generated settings. Interaction modes and other sensory outputs and inputs may vary depending on the technology used. In a later prototype, Thomas P. Caudell and David W. Mizell [68] used the phrase “augmented reality” for the first time to describe their system.

In contrast to VR, their method displays rudimentary wireframes, outlines, markings, and text superimposed on the real world. In a study titled “A Taxonomy of Mixed Reality Visual Displays” from 1994, Paul Milgram and Fumio Kishino [69] first used the concept of “mixed reality” as a term that embraces existing and forthcoming technologies that would enable digital material to interact with real-world items where people engage with digital objects as if they were real, including AR. They explained the methods and technologies, suggesting a “reality-virtuality continuum” where real and virtual are positioned at opposite ends. In between, mixed reality encompasses “augmented reality” and “augmented virtuality,” which are fusions of physical and digital in different ways. AR systems overlay virtual features over the actual world to augment it, while in AV systems, physical elements are placed into a virtual scene. With the advent of increasingly sophisticated technologies that allow for a range of engagement strategies and new concepts, Milgram and Kishino’s continuum has been altered or extended. For example, Mann [70] emphasized the ability to change actual conditions by adding, eliminating, supplementing, enhancing, or modifying via mediation, and he introduced two new concepts: “mediated virtuality” and “mediated reality.”

The discussions and definitions of the virtual-real dichotomy are not only the subject of computer science; on the contrary, the definition of “real” is one of the substantial concerns of ontological studies, mathematics, and semantics. For instance, Plato suggested that the real is composed of two distinct parts. He describes the things that can be perceived as “forms” in the physical world and more abstract entities, such as mathematical objects that exist outside of spacetime, as “ideas.” However, the word “realism” frequently has an opposing connotation, so Plato’s categorization is defined as “idealism” to refer to the ideas that exist solely in the mind [59]. With the advances in scientific studies throughout history, definitions have been transformed. Based on the discussions of Henri Bergson [71], Gilles Deleuze (1966), a French philosopher, defines the virtual as “real without being actual and ideal without being abstract” [72] Following Bergson’s concept of the possible instead of the virtual-real opposition, he identifies virtual and actual as elements of reality and places “possible” as the opposite of real. This way, he explains the relations between body, materiality, mind, and abstraction. According to Deleuze, the virtual cannot be defined as separate from the real since it can be shared, interactable, and sensible. He defines “real” as tangible things, including actual constructions that are physical and virtual constructions that are not physical but still interactable. On the other hand, similar to platonic idealism, he puts possible as opposed to real to explain that the constructions only continued their existence in minds. According to him, virtual-actual dualism can produce more procreative results than possible-real opposition [73].

Virtuality has a fragmented meaning that depends on what we accept as real. However, it is a representation of what is possible or real, reflecting them through various kinds of representational lenses. It can become an absolute reality within its nature. The phrase "virtual reality" has a well-established meaning that refers to computer-generated environments surrounding the user and concealing the actual world [74]. Augmented reality refers to the superimposition of computer-generated content on the actual environment. On the other hand, the term "mixed reality" is used in a wide variety of contexts, making precise definitions difficult. The development of robust technologies that can sustain real-time rendering and interaction with devices such as headsets and smartphones has expanded the use of and ways of interacting with digital content [75]. VR headsets like the HTC Vive, Oculus Rift, and Oculus Quest provided consumer-friendly VR experiences, which created a surge in the study of augmented, virtual, and mixed worlds. Mixed reality experiences, which bridge the gap between augmented and virtual worlds, are the product of recent technical developments. Experiences have begun to blur the lines between the actual world and the virtual one with mixed reality, which allows the interaction of actual and virtual in the Deleuzean sense.

2.4.2. Presence, Embodiment, and Experiencing Architecture

Presence refers to the feeling of being physically present in a given location, whether that location is real or virtual. It is the sensation of being in a place and is often experienced in virtual reality environments [76]. Several factors can contribute to the sense of immersion and presence in VR. Sensory immersion refers to the realism of the sensory stimuli provided by the virtual environment, such as sight, sound, and touch. Spatial immersion refers to the believability of the virtual space as a real, three-dimensional location that the user can navigate and interact with. Cognitive immersion refers to the level of engagement and absorption the user experiences while interacting with the virtual environment and performing tasks or activities [77]. By creating a realistic and believable virtual environment and engaging the user's senses and cognitive processes, VR can create a strong sense of immersion and presence. The sense of presence is influenced by both physical and cognitive factors and can be affected by both the virtual environment and the user's state of mind [78].

Virtual worlds are immersive environments that rely on technology to create and experience spaces, objects, and people with whom users can interact. They differ from actual worlds, which can be perceived and interacted with through the human body's sensory systems alone [48]. Our bodies serve as information acquisition, processing, and display systems, allowing us to absorb energy fields from the actual world, process and store knowledge, and emit information through verbal and nonverbal communication. Presence, or the feeling of one's body existing in a given space and time, is fundamental to communication and can occur in both real and virtual environments. The concept of embodiment, or the feeling of having a body, has also been discussed in relation to the presence in virtual environments. Research has shown that having a virtual body in immersive virtual reality can contribute to the sense of being in a virtual location. There are three subcomponents of embodiment: the sense of self-location, the sense of agency, and the sense of body ownership [76].

The idea of embodiment, which refers to how the body shapes and is shaped by our perception and experience of the world, was emphasized by Merleau-Ponty in his philosophy [26]. Merleau-Ponty argues that the body is not just a passive tool or biological entity through which we engage with the outside world but rather an active participant in processes of perception and understanding and a source of significance. Our bodies serve as both the vehicle through which we interact with the outside world and the means by which we express ourselves and interact with others. In this sense, the body is crucial to our subjectivity and understanding of the world [79].

Embodied cognition is the idea that cognition, or the mental process of acquiring knowledge and understanding, is influenced by and interacts with the body's systems [80]. People generate mental representations through physical simulations, situated actions, and bodily states. Grounded cognition and learning can occur at various levels of mental processing, including abstract internal representations. Simulation is the process by which the brain captures and integrates information across the body's modalities, such as sight and sound, and stores it in memory [81]. When someone thinks about an experience or idea, the brain reenacts the perceptual-motor and introspective states that were stored during the interaction with the physical world. Situated action, or how the body interacts with the environment in specific ways, also shapes thinking. For example, body position can influence metaphors and affect the interpretation of experiences. Unconscious facial expressions and body posture can influence feelings and responses to stimuli [48].

The embodied mind theory suggests that our thoughts, understanding, and knowledge are closely connected to our physical experiences [82]. This means that our ability to comprehend and, therefore, our identity, can be changed through new experiences and situations. According to this perspective, accepting fixed knowledge as the complete truth ignores the constantly changing nature of experience. Christian Norberg-Schulz argued that nouns are linked to place, prepositions are linked to space, and adjectives are linked to character. According to this idea, places can be identified by nouns, implying that they are considered real entities that exist. Norberg-Schulz also defined space as being represented by prepositions such as "at," "in," "within," "on," "upon," "to," "from," "along," and "next." This relationship demonstrates that language, the brain's sense-making mechanism, and bodily experience are closely connected. The words we use, including nouns, prepositions, and adjectives, reflect our embodied mind through our experiences. Space serves as a mediator between mental and physical abilities.

According to Heidegger, building is not just about constructing physical structures, but also about creating a sense of place and belonging. He suggests that dwelling is not just about living in a physical space, but also about being at home in the world and finding meaning in one's surroundings [83]. The concept of the genius loci can be understood as the spirit of a place that shapes the character and atmosphere of a location. By understanding and working with the unique qualities of a site, architects and designers can create spaces that reflect and enhance the surrounding area's character, and contribute to a sense of place and belonging [84]. Embodiment, in this context, refers to how people's physical and sensory experiences of a place shape their perceptions and emotions. By designing spaces responsive to a site's physical and cultural elements, architects and designers can create environments that are not only functional but also meaningful and emotionally resonant for the people who inhabit them. Around these concepts it can be said that the architectural environment should reflect the unique qualities of the site and the people who will inhabit it, the dwelling should be a place where people find meaning and belonging and where the experience shapes thinking [83].

Luck [20] states that during the design process through bodily engagements, certain acts that may appear incongruous have a deeper function. These movements, which pertain to the design of a structure, are intended to symbolize something and give a transient visual depiction of architectural concepts and the anticipated sensation of movement inside the architectural form. The phrase "aesthetic becoming" reflects the creative process behind the emergence of these behaviors. The relationships between a building's physical form, how it is experienced, and the reactions it produces are subjective, intuitive, and multifaceted.

In "Experiencing Architecture," Steen Eiler Rasmussen [85] discusses the importance of sensory experience in the appreciation of architecture. He argues that architecture should be evaluated based on how it is experienced by the user rather than solely on its aesthetic or functional qualities. Rasmussen believes that the sensory experience of architecture is integral to our understanding of and interaction with the built environment. He explores how various sensory experiences, such as sight, sound, touch, even smell, and taste, contribute to our perception of a building or space. Rasmussen explains the way of experiencing architecture, based on the perception of solids and cavities, figure-ground relations. According to him rhythm, scale, proportions, sounds, lighting, color, and texture are essential features of the architecture that creates the experience. He explains the observation process of figures in space and the mental processes that humans have. Mental "images" of objects express the contraposition between the vacant and the full, the mass and the emptiness, and the solid and the cavity. The solids are enclosed containers and form the cavities (spaces) that they contain. He divides the production and interpretation processes of architectural forms into two as solid minded and cavity minded. One can start with a simple framework and add to it, or one can carve out certain components from a large solid to start. The spaces formed by carving the caves are one of the most obvious examples of cavity-minded architecture. On the other hand, creating forms by combining solids or shells of the voids is a solid-minded approach. On a different scale, the buildings also contain both solids and cavities. Therefore, he explains architecture as "the art of playing with solids and cavities."

To understand these complex reactions studies based on quantitative measurements have been conducted. Ergan et al. [86] conducted a quantitative study using biometric sensors, and an electroencephalogram (EEG) to assess the effects of the architectural environment. According to results, different lighting settings, color, presence or absence of visual cues such as entrance, landmarks, and dimensions of the architectural elements can change the perception of the space affecting quantitative measurements. According to Daniel [80], the layout and visual accessibility of a space can impact stress levels because understanding and familiarity with the environment can help maintain a sense of spatial orientation. The geometric patterns of pathways within the space can also influence cognitive complexity.

In addition to being essential for the visual experience, color, and colored light have an impact on human emotions, behaviors, decision-making, and health [87]. Geslin et al. [88] and Roohi and Forouzandeh [89] have conducted several experiments that demonstrate the design potential of color and light in video game environments to successfully evoke players' psychological feelings, resulting in a high level of immersion as well as presence.

2.4.3. Interaction and Interface

A user interface (UI) is a means of communication between a user and a computer system or application. Personal computers typically utilize a graphical user interface (GUI), which utilizes input devices such as a mouse and keyboard, and output devices such as a display screen using visual elements, such as icons, buttons, and menus [90]. Effective interface design is crucial for ensuring a satisfactory user experience in both PC and immersive environments. The interface should be intuitive and aesthetically pleasing to promote usability. However, most interaction interfaces are not natural for the untrained user. Integration of lessons from the fields of human factors psychology and human-computer interaction into the interface design provides the opportunity to decrease effort and time for adaptation.

There are different types of interfaces defined and created. Form filling involves the user entering data into a pre-defined form or template. This method is often used to collect information from users, such as in online surveys or registration forms. It is one of the most suitable methods for novice users [9]. The term "direct manipulation" was first used by Ben Shneiderman [91] to describe a certain manner of interaction that can be linked to Sutherland's sketchbook [63]. The expression implies the notion that objects of interest can be directly controlled and displayed as recognizable objects. Direct manipulation involves the user interacting with on-screen objects in a way that directly affects their behavior. For example, a user might drag and drop an object on a computer screen to move it, or resize it by dragging a corner of the object. A command language is a set of instructions or commands that a user can enter to interact with a computer or software program. Command languages are often used in text-based interfaces, such as in a terminal or command prompt. The command language, as one of the earliest forms of interaction style, is still being used by operating systems and also modeling software. Natural language processing (NLP) is a type of interaction method that allows users to communicate with a computer or software program using natural, everyday language, rather than a specific set of commands. NLP is often used in voice assistants and chatbots [92].

Immersive environments may require more interactive interfaces that utilize specialized input devices, such as motion controllers or haptic feedback devices. There are several different interaction methods that can be used in immersive environments. Head tracking often includes sensors that track the movement of the user's head, allowing them to look around the virtual environment as if they were physically present in it [93]. Some immersive systems use sensors or hand-held controllers to track the movement of the user's hands, allowing them to interact with virtual objects using gestures or by grasping and manipulating them. Voice control allows users to issue commands or interact with virtual objects using their voice. Eye-tracking technology allows users to interact with the virtual environment by looking at certain objects or areas [94]. Sensors or body-mounted controllers track the movement of the user's entire body, allowing them to walk around and explore the virtual environment as if they were physically present in it. To effectively manipulate objects in virtual reality environments, interaction techniques should allow for at least one of the following: object selection, object positioning, and object rotation. The design of these techniques, which often involve the use of hand manipulation, plays a significant role in the overall user experience of a virtual reality environment. One common approach is to provide the user with a virtual hand, which is a 3D cursor that follows the movements of the user's actual hand and can be used to select and manipulate objects by touching them and positioning the virtual hand within the virtual environment. This technique is intuitive because it mimics real-world interactions with objects, but it is limited to objects within reach of the virtual hand [95].

2.4.4. Usability, Acceptance, Trust

Technology acceptance refers to how willing people or organizations are to use a certain technology. By understanding what influences a person's or organization's acceptance of technology, designers and developers can make more successful and appealing technologies [96]. Usability is defined by International Standards Organization (ISO) as "the extent to which specified users can use a system, product, or service to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [97]. It defines how easy it is for someone to use a product or system to accomplish what they want to do. It can impact how well the user performs, how efficient they are, how satisfied they are with the product, and their overall experience. The user's cognitive abilities and limitations and the design of the system's interface, organization, and structure can impact the level of usability [98].

According to ISO, trust is "a degree to which a user or other stakeholder has confidence that a product or system will behave as intended" [99]. The relationship between trust in technology and usability has been previously studied in the HCI domain. Salantri et al. [98] examine the relations between usability, technology acceptance, presence, and trust. According to their study, all three measurements affect the level of trust, but this relation is reciprocal. Being a multidimensional concept, dimensions of trust in relation to technology have been studied by many researchers [96], [100]. Lippert and Swiercz [96] state that there are three dimensions that construct trust between users and technology. The ability to predict that technology will adhere to previous performance criteria is a prerequisite for predictability. A technology's perceived dependability in certain situations determines its perceived reliability, whereas its perceived usefulness determines its perceived utility.

2.4.5. User Experience

User experience (UX) refers to a user's overall experience as they interact with a product or service, including aspects such as ease of use, functionality, and overall satisfaction with the experience. According to ISO, user experience is "a person's perceptions and responses resulting from the use and/or anticipated use of a product, system, or service” [101]. The user experience design should focus on creating meaningful, engaging, valuable, and aesthetically pleasing experiences for the user considering the user’s needs and desires, as well as the goals of the product or service, in the design process [102]. Additionally, designers need to shift their focus from technology-driven to human-driven innovations to create experiences that truly meet the needs and wants of the user. The process of constructing meaningful experiences can involve conducting user research, creating user personas, and testing and iterating on designs to ensure they meet the desired user experience [103].

It is important to understand several key concepts to ensure a positive user experience in virtual environments. The behavior of users in virtual environments can be influenced by various environmental features such as lighting, positioning, orientation, and physical structure of the space. and navigate through the content. Navigation in virtual environments is typically an exploratory process, and the virtual space has a three-dimensional structure that should allow users to explore different paths. An effective environmental design supports user navigation and maintains a sense of orientation within the virtual environment which requires incorporating architectural knowledge into the design and development of all spatial elements for better environmental awareness [103]. Customizability in virtual environments refers to the capability of users to adapt and modify the environment to fit their individual preferences. Customization can be achieved through various means, such as selecting a personalized avatar, modifying visual settings, and creating custom spaces within the virtual world [104]. Responsiveness, on the other hand, refers to the quickness and dependability of the virtual environment’s communication channels. It encompasses the speed at which the environment reacts to user inputs and the stability of the underlying technology. For instance, a virtual environment with high responsiveness would quickly and accurately respond to user actions, such as the movement of an avatar or the manipulation of objects [90].

Feedback in virtual environments is the presence of clear and informative cues to the user through visual and audio means. Feedbacks encompass a wide range of elements, such as notification alerts, visual representations of the status of an action, and audio cues that offer guidance. For instance, a virtual environment might provide audio feedback to indicate a successful action, such as successfully opening a virtual door, or visual feedback to indicate the completion of a task, such as the display of a “task completed” message. These elements allow users to personalize their experience, receive timely and accurate responses to their actions, and receive clear and informative feedback about the status of their actions and the virtual environment [105].

2.5. Autonomy, End-User Development, and Meta-Design

In the context of technology, the power dynamics of heterotopia can also play a role in the design and development of software and systems. The autonomy of users refers to the degree to which users have control over their interactions with a product, service, or system [106]. Designing for user autonomy involves creating systems that allow users to make their own choices and decisions. Cultures are shaped by the media and tools that people use. In the past, the design of most media separated producers and consumers, with television being a particularly prominent example. This has led to a consumerist mindset, where individuals are often treated as passive consumers rather than active problem-solvers. Later, widespread use of the Internet, mobile phones, and personal computers created a shift from a culture of passive consumption to one of active participation, facilitated by end-user development and meta-design. This shift has led to the emergence of new roles such as "prosumers," "professional amateurs," and "social production and mass collaboration," and has put an emphasis on "open systems" and "user-generated content" [27].

End-user development refers to the process by which non-expert individuals are able to design and create their own products or solutions, rather than relying on technical professionals. EUD was first proposed by Friederike Fischer in the 1980s as a way to empower users and enable them to create custom solutions that meet their specific needs and requirements [106]. This approach enables end-users to take ownership of problems and become self-sufficient in finding solutions by providing them with tools and resources that allow them to create or modify software or systems without needing to have professional programming skills. Making custom changes to video games, composing illustrations and videos via software, and producing architectural designs with modeling tools can be given as examples. The goal of EUD is to empower users and give them more control over the software and systems they use. It can also help to foster a sense of ownership and engagement among users, as they are able to create solutions that are tailored to their specific needs and requirements [10].

Meta-design is a methodology for designing systems and environments that enable end-users to create their own content, or, in other words, it is an approach to "designing for designers" [106]. It is applicable to a variety of contexts, including programming, software engineering, architecture, education, and interactive arts. Meta-design principles may include considering the needs and abilities of end-users, facilitating collaboration and co-creation, and promoting user autonomy and agency. When designing for user autonomy, the aim is to create a "design space" that gives users the freedom to make their own choices within the limits of the system. Meta-design considers the ways in which a system can empower and enable users to make their own choices and decisions [107].

2.6. Discussions on Architectural Production and Automated Generation of Built Environment

Evans [108] focused on the ways in which paintings and other visual representations of architecture are created. He studied the history of painting from the time when artificial perspective was first developed by Brunelleschi and Alberti until the present day. Alberti, considered the father of artificial perspective, discouraged architects from using it because the straight lines it relied on could not be accurately measured. On the other hand, many architects have continued their search for an accurate way to visualize and record their designs and impressions of existing buildings in three dimensions. There is growing evidence to suggest that the type of design media employed can impact how design issues are examined and determine the characteristics of the final architectural product [109]. Today, there is debate about the impact of computer graphics programs on the design process.

Evans took a nuanced approach to the topic of projection and emphasized the complexity of its relationship to the creation and interpretation of architecture, often pointing out how designers' reliance on geometry can be metaphorical rather than based on actual measurements. Wienand [110] suggests that the languages of words, drawings, and models that architects utilize are crucial for conveying architectural ideas. Using a variety of languages can improve comprehension of design challenges and lead to more intricate and varied environmental forms. Incorporating multiple languages is considered a useful technique for deepening understanding and furthering architectural thought.

According to Frampton [111], there should be a close relationship between architecture and the physical construction of buildings in the material world. He believes that digital design on a computer is only truly useful if it meets the practical, physical requirements of building in the real world. However, following the constraints of the material world may hinder the ability of designers to explore and experiment with ideas in the virtual world of computers.

Eisenman [112] discusses the impact of computers on architecture, specifically the shift towards a focus on simulation and appearance over physical existence. He identifies this as a challenge to the field of architecture due to the influence of the "electronic paradigm." On the other hand, he recognizes the potential for computers to facilitate creative design, stating that they allow designers to create objects that may not be possible to make by hand. He also mentions the use of computers in the design process as a means of constantly refining and improving concepts through the use of virtual models.

Computer graphics are generally criticized for their inevitable reflection on architectural products and appreciated for providing accurate and flexible representations. While 2D drawings are still widely used for communication during design and construction processes, hybrid techniques are preferred including digital and physical models, perspective and isometric drawings, or renderings, especially in the design period.

Just because architectural designs are often simplified or abstracted in their representation, it does not mean that the final structure will lack physical materiality. The use of digital technology in design can be seen as a tool that allows architects to create more complex forms and easily make changes to their designs. However, it does not fundamentally change the nature of architectural design and construction. The computer allows architects to create new designs and objects that were not possible before, which allows them to create more complex and detailed designs and control the lighting and texture of their designs, creating a more realistic and tactile experience [113].

The intersection of architectural production with fields of technology, biology, and digital fabrication has created new paradigms such as "performative architecture" and "parametric architecture." Performative architecture refers to the idea that architecture should be designed not just for its visual appearance but also for its ability to perform certain functions, such as regulating temperature, filtering light, and collecting energy. The area includes the use of digital fabrication techniques to create structures that can respond to their environment, such as building facades that can change shape or color in response to changes in temperature or light, exploring the use of natural materials and forms, such as those found in biology and nature [114]. For example, Oxman's works [115], [116] emphasize the importance of designing architecture that is sustainable and responsive to the needs of the environment and the people who will use it to create architecture that is functional and adaptable to the changing needs of the environment and society.

Parametric design in architecture is a design methodology that utilizes a set of predefined parameters or rules to generate design options. Using parametric design enables architects and designers to produce intricate, customized, and adaptive designs that can be efficiently altered and optimized according to specific design criteria. The implementation of parametric design commences with establishing a comprehensive set of design objectives, limitations, and parameters, such as building dimensions, the number of rooms, and energy efficiency [117]. The parameters established in the initial stage are then transformed into a mathematical representation of the design, which can be easily manipulated and evaluated using computer-based software. The utilization of parametric design confers several benefits, one of which is its capability to afford a significant degree of adaptability and revision in the design process. Architects and designers can experiment with various design alternatives and assess their outcomes under varying conditions, such as shifts in light, temperature, and wind, thereby enabling design optimization to fulfill specific performance objectives such as energy efficiency and structural stability. Moreover, parametric design is also instrumental in generating complex architectural geometries, including freeform shapes, that are challenging to attain through conventional design techniques [118].

The advancement of technology has resulted in the emergence of innovative forms and shapes in architecture, such as those arising from biomimicry and generative design. It is noteworthy that parametric design should not be considered as a solitary approach but instead as a tool that can be utilized in conjunction with other design methodologies to assist architects and designers in exploring and optimizing their design possibilities [119]. The utilization of parametric design techniques, which enable the generation of forms through digital design methods, can be evaluated in real-time within the virtual environment in which they are created. This offers the opportunity for the discovery of unexpected and unique design solutions. Thus, the integration of parametric design and virtual environments presents a promising and dynamic approach to the design process, providing architects and designers with the ability to test and refine their designs in a simulated environment before physical implementation.

The existence of certain parameters and rules makes it possible to produce architectural designs via algorithms and techniques that can be found in computer sciences. Many advanced techniques have been created to provide automation based on architectural representations such as Markov models, n-grams, multi-dimensional Markov chains, convolutional neural networks, auto-encoders, generative adversarial networks (GANs), graph neural networks (GNNs) [120]. Most of these newer techniques aim to create completely autonomous methods. Many researchers have developed methods for the automated creation of structures and floor designs, but only a small number of them allow for modification of the algorithm’s final output [121].

Also, techniques that are based on training with floor plans produce 2D outputs which require additional techniques to provide a third dimension. However, from the meta-design perspective, this study aims to provide "design space" for the users while providing more comprehensible and adaptable techniques which can increase the resistance of individuals and the framework. Therefore, we analyzed approaches that can provide various levels of automation and 3D outputs such as procedural content generation.

In the process of procedural content production, algorithms and patterns are used to generate digital assets in an automated fashion with very little involvement from humans. In game development, algorithms are used to construct complex systems including road networks, buildings, live animals, landscapes, and plants [22]. These complex objects may be found in video games and other interactive entertainment. In addition to computer science, procedural content creation is being researched in other domains, such as biology, architecture, urban studies, and psychology, which has led to a surge in interest from a group of academics from a variety of disciplines [122]. Autonomous tools are being used to accelerate and enhance the task of creators, but it is possible that these tools will not be able to create rich user experiences in the same way that human-generated material does. It is possible to change the level of autonomy that the algorithm possesses to stimulate more creative thinking. Researchers are investigating ways to produce high-quality assets with or without the assistance of humans, leading to the creation of novel methodologies as the significance of PCG in production increases [123].

A significant number of empty structures with no internal divisions or linkages have traditionally been generated using large-scale procedural modeling of virtual landscapes. Many solutions have been proposed to address this issue, including rearranging the tiles, expanding the space, tying the interior to the exterior, and subdividing the property. Using tile placement techniques, the domain is divided into segments, and the resulting grid is filled with tiles that represent the different building elements. Inside-out algorithms are used to arrange the rooms according to the needs for room connection without being confined by the boundaries of the building. Room seeds are distributed throughout a building using growth-based algorithms, and as a result, the rooms progressively fill the interior space and grow to their full size [124]. The user determines the forms and positions of the rooms in a restricted growth-based method for constructing floor plans that were created by Lopes et al. [125]. The rooms are then altered so that they are square, and the empty space is subsequently furnished with more irregularly shaped objects. With the use of doors and windows, this method enables the partition of the floor plan, allowing for the connection of rooms that are close to one another. According to Lopes et al. [125], this approach's effectiveness is facilitated by its simplicity and effective data structures. A method for automatically creating rectangular floor plans based on an existing graph derived from floor plans was suggested by Wang et al. [126] called the "Graph Approach to Design Generation." They developed a method to alter the rooms based on the application of two transformation principles through the addition or removal of elements by mapping the floor plans to connection graphs. For each room they build, the approach also enables users to define the maximum width-to-height ratio.

Subdivision algorithms divide the interior area into rooms based on building constraints. The binary space partition (BSP) method uses hyperplanes to recursively split a space into convex sets, and the final scene is represented by a BSP tree data structure. Baron [21] researched five approaches for building rooms and corridors: Random Room Placement, BSP Room Placement, Random Point Connect, Drunkard's Walk, and BSP Corridors. These methods are used to build procedural content that may be used in both 2D and 3D applications. Yang et al. [127] presented a reconstruction approach for room layouts in indoor environments to provide high-quality polygonal representations of interior spaces. Voxel-based room segmentation and space partitioning are used in this technique. The method uses room semantic information to split subspaces.

Building designs using cellular automata are distinct from other methods. Each cell in a cellular automaton is given a set of rules, which it subsequently applies to its neighbors. There is a limited range of cell states that cells may exist in. Kvan et al.'s research [128] demonstrates how the inclusion of many cell kinds and sizes in a single CA model may aid in the discovery of architectural shapes. A conceptual framework for CA integration into the design process was also presented. For high-density residential construction types, Khalili-Araghi and Stouffs [129] study CA systems. CA uses rule definitions to address solutions for architectural issues including density, accessibility, and natural light. This is possible because CA can build sophisticated rule definitions. Cruz et al. [130] claim that the standard CA cell shapes may be changed to provide a variety of architecturally sound forms that can create aggregate spatial units to satisfy certain spatial arrangements.

CHAPTER 3

DESIGN RATIONALE AND STRUCTURE OF THE FRAMEWORK

Based on the review of the existing literature on heterotopias and discourse, a set of guidelines were produced to ensure consistency in methodology and provide a comprehensive framework. The system should (1) be capable of adapting its functions and provide dynamic power relations in order to facilitate resistance; (2) facilitate the "operating table" for multimedia and architectural elements allowing for the exploration and manipulation of these elements in a dynamic and flexible manner; (3) serve as a foundation for individuals to engage in the process of "self-formation" and provide a "focal point of resistance" through the construction of "authorities of delimitation" in collaboration with the system itself; (4) establish connections with other places through the creation of either an illusory space or a structured space comprised of "grids of specification"; (5) possess the capability to generate "liquid architectures" that are adaptable to the needs of users and present spatial qualities that are experienced through embodiment.

The study provides a methodology that emphasized end-user development and meta-design principles in order to empower users, establish a design space, and enable individuals with a range of skill levels to use and manipulate the system producing informal use cases. To help users become curators of their digital environments, mechanisms and features were chosen based on previous research in multimedia, architecture, and immersive technologies. The implementation details for VR, MR, and PC technologies are presented in the following sections, organized according to the flow and layers outlined in the methodology.

3.1. Virtual Museum as an Operating Table

In this study, a virtual museum is not simply a fixed presence in the digital realm but rather is conceived as a fluid entity that allows the user to manipulate and rearrange various elements. The process of designing a virtual museum is an ongoing one that involves both the documentation and organization of personal data and the construction of a virtual environment in which information can be creatively explored and interpreted. When personal data is organized and stored digitally, it becomes a digital archive, but when it is presented or displayed, it becomes an individual exhibit or, when multiple files are presented within a cohesive framework, a digital exhibition. The construction of "grids of specification" produces virtual museums, transforming personal archives into exhibitions.

Through our work, we sought to enhance the usability of the framework and simplicity in terms of the process and number of features. To do this, we introduced the concept of a "virtual museum" as a system for organizing and displaying digital content, including text, images, videos, 3D models, and audio. We designed two modes for this system: a "curator mode" for actively building collections, and a "visitor mode" for exploring them. In curator mode, users have the ability to create "heterotopias," which can contain and display a variety of media and are formed via architectural elements. To be able to provide automation for the reordering system of heterotopias, we used the categorization system according to traditional museum conventions (such as "painting" or "sculpture") and utilized additional data, such as the artist, location, and time period of each asset. The framework also recognizes the importance of personal interpretation and manipulation within the museum space. As such, we designed the system to be open to user input and customization. For example, the criteria used for sorting and grouping items (such as asset style, artist, location, and time) can be systematically manipulated by the user to create new and unique systems. In this way, the framework allows for both structure and flexibility in the creation of digital museum experiences.

3.2. Dialogue Between the User and the System

The quality of the hardware, system design, and interface all play a significant role in shaping the user's experience. The hardware, for instance, determines factors such as physical comfort, technical limitations, and the ways in which the user can interact with the system. The interface serves as a conduit for communication between the user and the system, influencing the user's level of autonomy and their ability to create heterotopias. The user's understanding and interpretation of the digital environment are guided by the interface and other factors such as interaction and navigation.

3.2.1. Programming Language and Development Environment

To ensure that hardware variations between VR and MR do not affect the results of this research, we employed a Head-Mounted Display (HMD) device called the Oculus Quest 2 to transmit audio and visual material. The Passthrough capability of the headset, which utilizes sensors to view a real-time image of the surroundings with virtual material, enables the blending of AR and VR, leading us to refer to it as mixed reality in this study rather than augmented reality. The Oculus Quest 2 is equipped with three sources of sensor data [131]. Hand gesture detection, physical context awareness, and the location of the controllers and hands are all made possible by continuous data streams. Users may traverse a virtual area using hand tracking and the Oculus Quest 2 Controllers as interactive devices (VE). The virtual environment allowed users to see every button on the controllers, including the hand position. The Oculus Quest 2 is designed to improve the user's immersion and presence in the virtual world by tracking their head movement and displaying the appropriate image in real-time [131]. This technology allows for natural interactions and a high level of immersion. The head-mounted display (HMD) comes with an adjustable head strap that enables the user to keep their hands free to use the controllers.

The Unity game development platform was chosen for the development of the utility because of its unique features compared to other platforms and its compatibility with the Oculus Quest 2. Unity is a versatile game engine that can be used on a variety of devices, including desktop computers, mobile devices, gaming consoles, and the web. It supports the C# programming language, which is an object-oriented, general-purpose language developed by Microsoft. Object-oriented programming (OOP) is a programming paradigm in which data and the code that manipulates it are bundled together into self-contained units called "objects." These objects are designed to reflect the behavior of real-world objects and can be used to represent real-world concepts or objects. OOP is characterized by the use of encapsulation, which involves bundling data and the code that manipulates it into a single object. Encapsulation allows for flexibility and the ability to add new features or modify the structure of the program, providing adaptability of heterotopias and resistance to users. In addition to Unity, the Microsoft-driven Mixed Reality Toolkit (MRTK) was used to provide a set of components and features for the virtual reality and mixed reality versions of the Framework. The 3D models were created using RhinoCeros and Blender and were enhanced using online 3D modeling platforms that offer copy-left models, such as CG Trader, Sketchfab, and TurboSquid.

3.2.2. Interface and Interaction

The user interfaces designed for the framework have been designed specifically to facilitate interaction with diverse technologies. However, it is not uncommon for novice users to encounter difficulties in utilizing such interfaces. To address this issue, we have incorporated principles from the fields of human factors psychology and human-computer interaction into the design of the UI to minimize the time and effort required for adaptation. While command language interfaces, which are frequently utilized in operating systems and modeling software, are highly versatile, their use may pose challenges for novice users and may not be suitable for all individuals. Therefore, we have excluded command language interaction from the design of UI other than hand gestures.

As opposed to command language interfaces, the form fill-in interaction style has been specifically designed for the use of non-expert individuals. Form-fill-in techniques have been employed for activities requiring multiple data inputs from the user. For instance, the dimension characteristics of the generating methods, and the URL provided are examples of the form fill-in style's implementation. Rather than utilizing blank input fields to directly specify and display the range to the user, sliders as a means of guiding the user through the predetermined criteria and facilitating the data entry process are preferred.

By choosing and carrying out actions from menus that are presented, it is possible to change the status of the system. Menu interactions are frequently employed and preferred since they are advantageous for inexperienced users, despite the possibility that this could cause slow performance for regular users. Instead of labels icons are used to indicate the command/menu items to improve memory and remove linguistic barriers.

To mitigate information overload and visual clutter, the items were grouped into submenus according to their roles (Figure 1). In the VR and MR versions, menus persistently follow the user unless the functionality is deactivated. In the event that the main menu is lost, a hand menu providing options to restart, quit, and summon the main menu is available (Figure 2). These options can be accessed through a hand motion and a controller button.

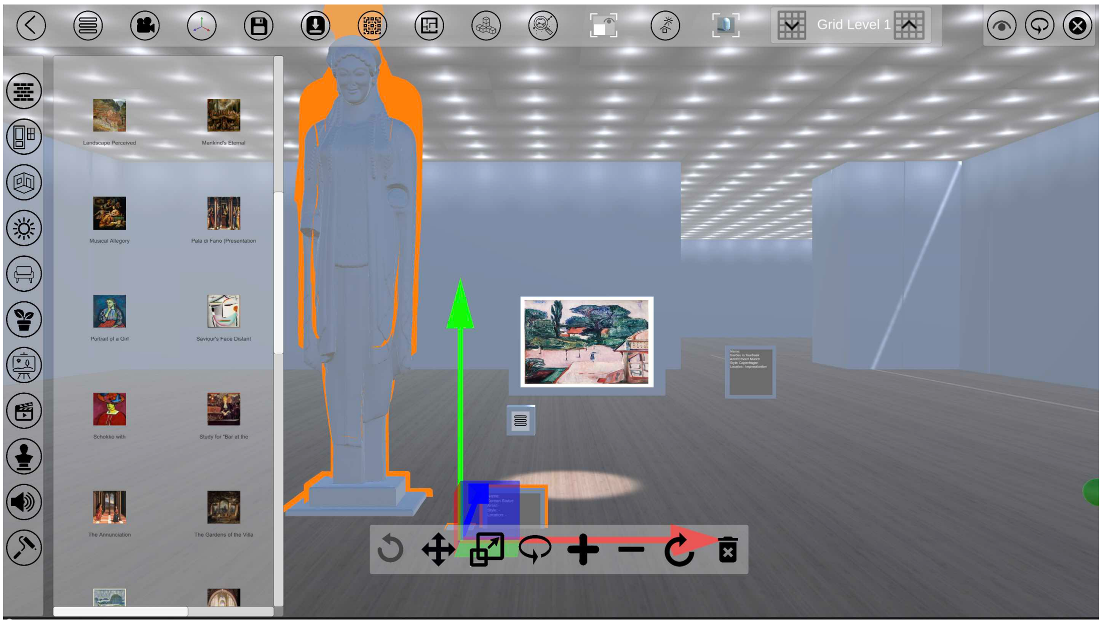

Figure 1: Direct Manipulation and interface.

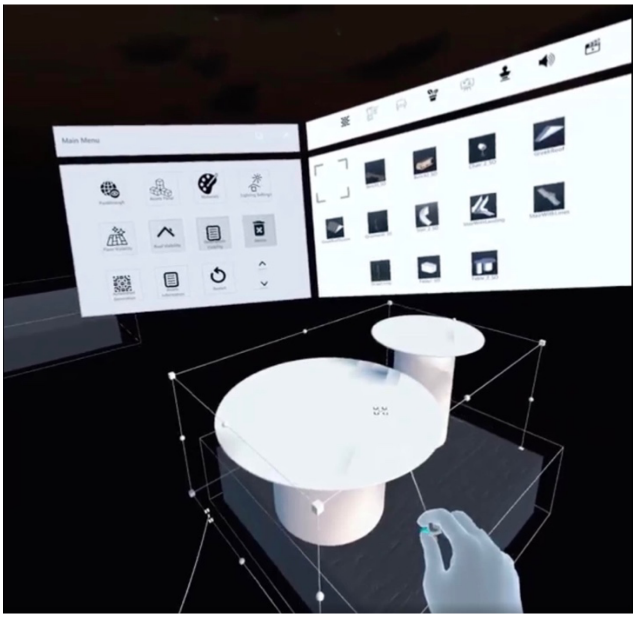

Figure 2: Direct Manipulation in VR environment.

In the construction process, a technique similar to the direct manipulation approach is employed. Depending on the version, selected items can be directly controlled using hands, controllers, a mouse, and a keyboard. Two alternative modes were developed: curator mode and visitor mode. This division serves to prevent accidental model modifications and eliminate UI components that are unnecessary and may distract users from their experiences. While the PC version uses the keyboard and mouse as input, for VR and MR versions, controllers and hand interaction are offered. The gestures are components of human-computer interaction that have become the subject of attention in multimodal systems. In this study, six hand gestures, namely point, select, release, teleport, call hand menu, and call main menu (Oculus) were provided with far and near interaction options (Figure 3). For all versions, the user can manipulate the elements including 3D UI elements, via scale, rotate or translate operations.

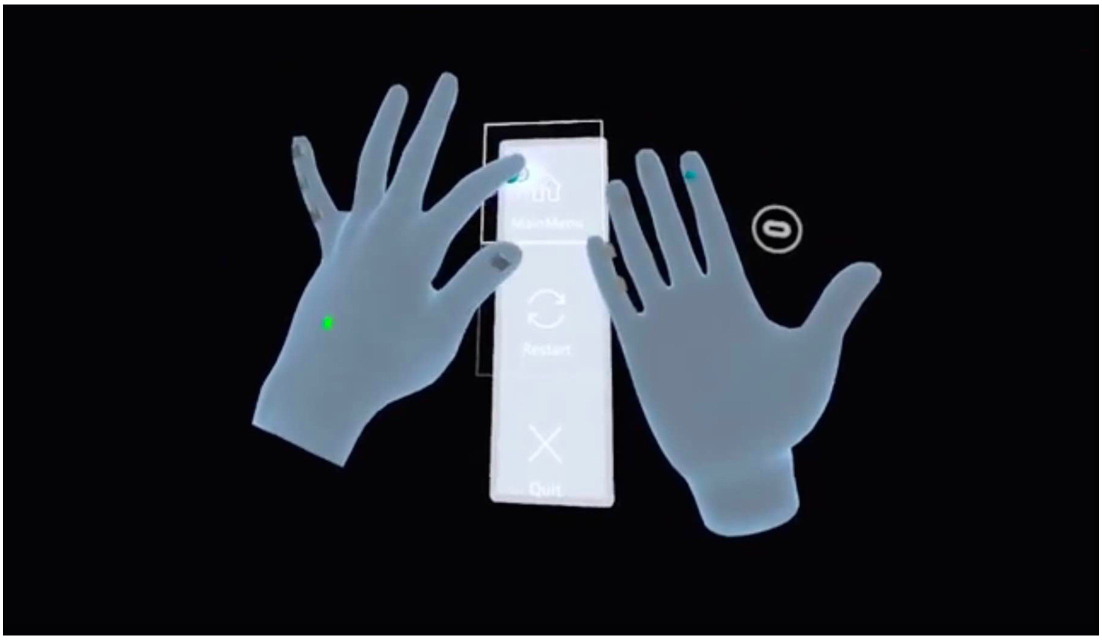

Figure 3: Hand Menu interaction.

3.2.3. Navigation

To allow users to craft their own unique virtual experiences, they must have full control over their navigation inside the digital environment and the freedom to explore and interact with the artifacts. This allows them to actively engage with the exhibits during the curating process, rather than simply observing them passively. This approach enhances the flexibility and engagement of the virtual experience. By cultivating the user's aesthetic sensibilities, the overall experience of navigating the virtual museum becomes more enriching and engaging.

We endeavored to ensure that all versions were as consistent with one another as feasible. However, to facilitate navigation and interaction for the PC version, it was necessary to employ various methods which are different from the other versions. The PC version offers four camera views: first-person, top-down, isometric, and isometric bird view. The W, A, S, and D buttons on the keyboard were selected to control the cameras' position and rotation, and a mouse scroll serves to zoom in or out while viewing the scene from a top-down perspective. In addition, the transport option in the control menu allows users to teleport every camera in the scene with a left-mouse click. Within the virtual environment (VE), users can navigate, walk, or teleport using controllers or hand gestures. Colliders that enable teleportation are defined by tags.

Objects with floor and ground tags allow teleportation. To prevent motion sickness, we did not include movement through controllers.

3.3. Content Layer as an Act of Self-Formation and Archival Practices

As a force of resistance, individuals should become “authorities of delimitation” within the boundaries of the system and assert control over the elements of the “surfaces of emergence.” Archival practices, as a method of constructing and analyzing discourse and its components, constitute acts of “self-formation” on an operating table. To provide automation for these transformations, a pipeline is developed that includes the importation of individual archives and their conversion into operable artifacts. Additionally, via sorting and grouping algorithms, assets of the users are stored in the form of archives, and analysis of the content is provided.

3.3.1. Importing Files and Authority of Delimitation of the Framework

The first layer of the delimitation is represented on the operation table in accordance with the framework’s media type classification. Five separate asset types of museum counterparts have been determined. Within these constraints, users are empowered to create a personal collection of 3D digital exhibits based on their interests and preferences, being a focal point of resistance. Text files in the .txt format, images in the .jpeg and .png forms, 3D models in the .obj and .fbx formats, audio files in the .mp3 format, and videos in the .mp4 format may all be converted into artifact displays. The user’s capacity to design a unique set of 3D digital displays based on their own interests and preferences is crucial. To achieve this, the user chooses the folder containing the files to be uploaded to the application using a customized file browser created especially for the PC version. Due to security restrictions of the headset, the VR and MR versions of the framework retrieve the assets using Google Drive rather than accessing a file browser. Therefore, Oculus’ virtual keyboard and an input box, where users may simply enter the file ID of the data file, are included to give this functionality. A direct Google Drive export link for a data file is produced by the framework based on ID. The file IDs of the objects that will be downloaded into the framework must be included in the data file.

3.3.2. Artifact Classes

In addition to assets, the user has the option of supplying a data file in .CSS or .JSON formats that includes specific features of the artifacts. The data columns are defined as the name, artist, style, location, time, size, and description. According to permissible asset types, five distinct artifact classes were derived from the basic class namely paintings, sculptures, videos, sounds, and text. Each artifact shares common characteristics such as name, description, artist, and style. Specific qualities are acquired based on the class, for example, paintings and sculptures possess location and size attributes. If the data is available in .CSS format, the framework automatically parses the data and extracts the assets as artifacts, depending on its class, Then, an algorithm will compare the data and files to find names that match, make dictionaries, and construct separate lists for artifacts, and check for names that match. The framework places the files in a specified data folder and sorts them according to their file extensions. Buttons are constructed for each file, and they are placed beneath the relevant panel automatically. The buttons display images taken straight from the file if it is a painting artifact. The file type is indicated by an icon for all other formats. Based on the file name, a label for the button is produced. In the absence of data, objects will be deployed without a description panel and with a generic scale, using the filename as their name.

3.3.3. Artifact Holders

By prioritizing end-user development, the system automates the process of converting personal assets into artifacts that are open to manipulation, allowing users to experiment with and make changes to the artifacts, and to determine the best position for them in both the virtual and physical worlds. To facilitate interaction, an artifact holder is designed for each artifact type, incorporating the scripts and elements required according to the principles of object-oriented programming. Holder objects, which occupy a higher level in the hierarchy and can be manipulated in terms of position, rotation, and scale, consist of several components. These include a label panel displaying brief descriptions, a game object containing the assets, a Details button to open the ArtCanvas panel, a collider for manipulation, and a grid object collection script to ensure the spacing between the artifact and label remains consistent (Figure 4). If dimensions are provided for a painting or sculpture asset, the container object for the asset is scaled accordingly, while the spacing between the artifact display and label is maintained. Each artifact holder also has features specific to the type of asset it holds. For instance, artifact holders of video and sound assets include play and pause buttons. When an artifact button is pressed, an artifact holder is instantiated based on the corresponding prefab. If data is provided, the label displays the name, artist, style, time, and location columns. The ArtCanvas panel provides an expanded version of the information and displays the description within the details section placed on the right side of the canvas. Visual representations of video, text, and painting artifacts and icons for sound and sculptures are given on the left side of the panel. Users can view a list of all assets they have uploaded in the artifact analysis panel, which presents the information organized according to the categorization of artifacts.

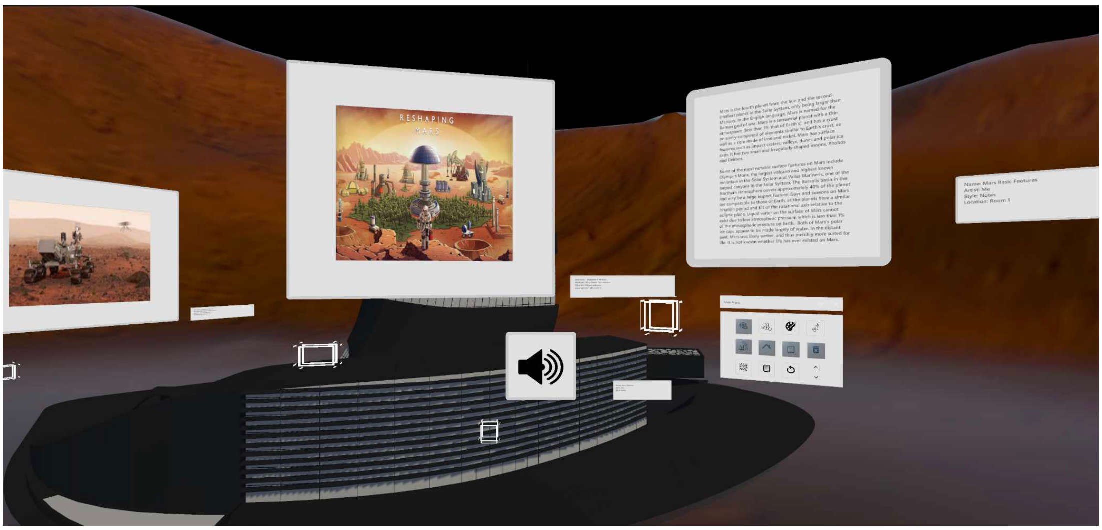

Figure 4: Artifact Holders in VR environment.

3.3.4. Analysis of Artifacts and Grids of Specification of the Framework

To make the asset archive easily accessible, the assets are initially sorted based on their formats. Data, if available, are arranged into columns and organized according to four key specifications consisting of three strings and one integer for each class: artist, style, location, and time. These specifications are displayed in the artifact analysis panel and can be used to calculate the dimensions. The resulting lists are displayed in the artifact analysis panel. These groups are also prepared to utilize PCG algorithms to calculate the dimensions of the rooms based on grouping options. Users also have the ability to generate various types of specifications based on the data types.

3.4. Spatial Layers as an Act of Self-Formation and Architectural Elements

The main purpose of using architectural elements in a virtual museum context is to arrange multimedia elements in a structured way, creating spatial "grids of specification". In this study, the notion of a "virtual museum" does not imply a traditional static entity. Instead, it expands the space and forms a "liquid architecture" around the user, with every digital object placed becoming information. In addition to serving as a partition for artifacts, place-production practices enable users to have "aesthetic becoming" experiences transforming the environment they are in.

The layers in a heterotopia illustrate the complexity and multifaceted nature of these spaces, each with its own unique meanings and functions. These layers can be understood as different levels of reality mediated by a variety of technologies. One layer of spatial meaning in a heterotopia is its actual physical location in the world and the context in which it exists. PC, VR, and MR technologies offer a range of connections with places and place production. Mixed reality technologies provide a link to the physical location, while the context allows for the transformation of physical space with digital elements or the creation of entirely digital places. Heterotopias have layers of spatial meaning that correspond to individual experiences. Through the incorporation of embodiment, technology offers a vast array of possibilities for users. In this study, we applied architectural practices in order to augment the transformative effects of heterotopias and provide an operating table for these practices through embodiment and presence. To create a user-friendly, generic framework, a review of architectural studies to identify essential features was conducted. In "Experiencing Architecture," Rasmussen [85] explains various factors such as the perception of solid and cavity forms, the differentiation between foreground and background elements, the size and dimensions of architectural features, the appropriate use of proportion and scale, the acoustics of the space, the lighting, the textures, and the rhythm all contribute to the overall sensory experience of a building or space. With this in mind, we sought to incorporate these elements within a technological landscape.

3.4.1. Tectonic and Non-tectonic Materialized Elements

To construct an architectural environment, we have identified several main components such as walls, floors, roofs, windows, stairs, and doors. In addition, we have also included two other categories: landscape elements and furniture. These components are all provided in separate panels. They are also available as default objects that can be edited in terms of position, size, and orientation. All objects possess the ability to be scaled, and also, we provided various scale options to enhance usability. The wall, floor, and roof tiles are also offered in distinct sizes, such as 1x1, 2x2, and 4x4. At the outset of the experience, the framework presents two distinct scale modes for virtual reality and mixed reality environments: human scale (1:1) and model scale (1:20). All models are automatically scaled according to the chosen option. Additionally, the size of vertical construction components is determined by the selected grid height.

3.4.2. Cohesive Spatial Elements

The integration of computer technology within the realm of architecture has led to a reevaluation of the fundamental concept of materiality. Rather than discarding the significance of physical materials, the utilization of digital tools has resulted in a paradigm shift in the way materials are employed and designs are generated. This shift necessitates users to adapt their design methodologies and objectives to account for the intricate interactions between various elements, as well as the capability to make modifications through parametric variations. As a result, techniques for visualizing and representing designs that can accommodate the heightened complexity and flexibility provided by digital technology. Within the Unity engine, textures are created by tiling 2D images. A variety of textures are offered for the wall, floor, roof, door, and window objects to ensure a cohesive look and ease of use. To maintain consistency, objects within the same layer possess identical material properties. In addition to this, we have incorporated sliders that permit the adjustment of RGB values for the materials utilized by the construction objects. Furthermore, we have provided a range of skybox materials for both VR and PC versions.

In the virtual environment, three distinct lighting methods are utilized: spotlights, light strips mounted on the ceiling, and directing sunlight. The lighting settings panel, which contains a toggle switch for each form of illumination, can be utilized to manage these lighting systems. Correlated color temperature (CCT) is a measure of the color of light emitted by a source. It is measured in degrees Kelvin (K), with values below 3000K appearing more “warm” (red or yellow), values between 3000K and 5000K considered neutral, and values above 5000K considered cool (blue or white) [132]. In this study, we defined the minimum Kelvin value as 1000 and the maximum value as 15000, and we used Unity’s core modules to estimate the RGB (red, green, blue) equivalent of the selected value. A slider that utilizes Kelvin values is provided to users to determine the color of the light (Figure 5). The virtual environment also offers a selection of skybox elements for use.

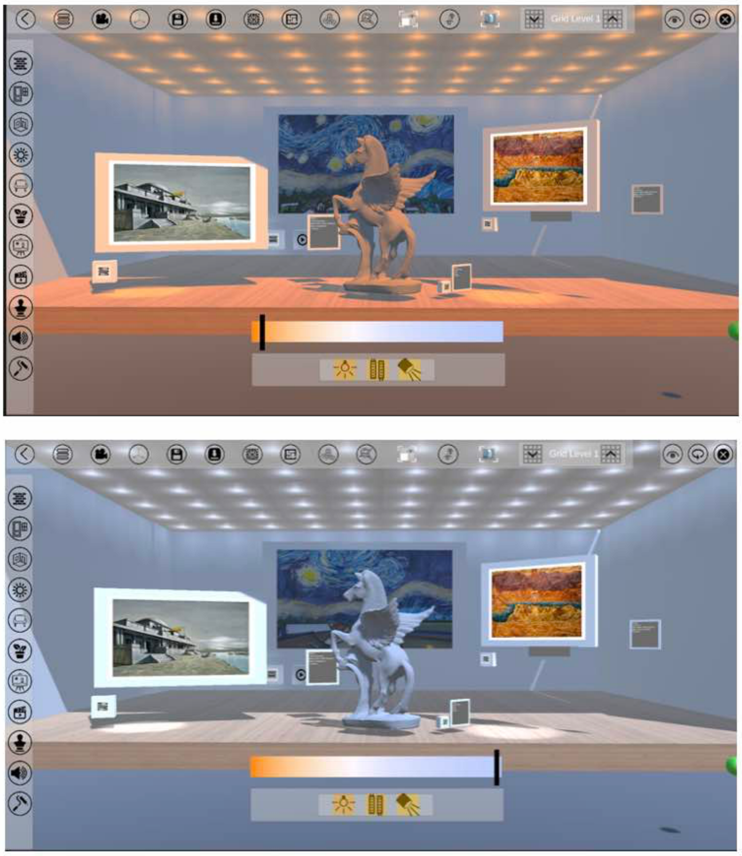

Figure 5: Lighting Settings.

3.4.3. Placement and Grid System

Users can determine the placement of artifacts and existing models in both virtual and physical environments through manipulation. The grid system is used to ensure that the assets are properly aligned. The user has the option to adjust the height and configuration of the grid, which will affect the height of the walls and the number of floors. To provide greater flexibility and reuse, three Scriptable Objects (SOs) have been created for all placeable objects, including artifacts. SOs are a type of asset in Unity that allows data to be saved in an asset file rather than as a mono behavior attached to a GameObject. This enables data to be stored in a manner that is independent of any specific game object and facilitates the reuse and sharing of data between different parts of the framework. The initial code on the scriptable objects adds the appropriate additional scripts for interaction and hierarchy based on the type of SO. The first type of SO is for floor objects, which can only be placed on layers designated as ground. The grid system is utilized for snapping these objects into appropriate positions and for storing their position data. The second type encompasses vertical elements such as windows, walls, and doors that are placed along the edges of floor tiles. Each floor object is equipped with four colliders located at the corners, enabling the grid system to snap and rotate vertical elements according to the edges of the floor objects upon collision during placement. The third category of Scriptable Objects (SOs) encompasses a range of other elements and artifacts that can be placed anywhere. Both ghost objects and placed objects are provided as two variations of a single prefab for all types of SOs. A ghost object will emerge and move in sync with the mouse in the PC version and the pointer in the MR and VR versions when the instantiation button is pressed. Depending on the version being used, the user must either click the left mouse button, perform a selecting gesture with the right hand, or hit the right trigger to insert an object. The user can cancel the selection via the right mouse click, and the select gesture with the left hand or left trigger. A toggle is used to initiate the delete function that, when turned on, enables users to remove the chosen items. If the model scale is chosen, the grid system is placed on a table and all spawned objects become child objects of the table. This allows the scale and movement of the objects to be converted and controlled through the table.

3.5. Architecture and Archives Combined: Automated Generation of Built Environment

This system utilizes algorithms that provide "grids of specification" in 3D space based on archival data, enabling rapid prototyping for architectural practices. In line with the discussions on architecture, heterotopias, and meta-design principles concerning power, autonomy, and control, we have modified these algorithms to provide users with a design space and a level of control. These algorithms can generate content based on user data, and the resulting content can be customized as required by the objectives of this study. Through the use of algorithms that can produce and alter content based on user input, the suggested framework is able to offer adaptive and compatible design solutions (Figure 6).

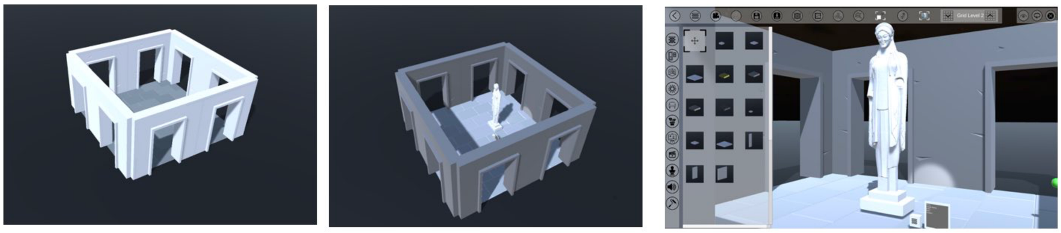

Figure 6: Output of Room Generation Algorithm after user intervention.

Rasmussen [85] discusses how people's mental representation of elements involves a contrast between "empty and full", "mass and emptiness," and "solid and cavity" in his book "Experiencing Architecture." This concept relates to how people perceive figures in space and their thought processes. Concerning the creation and understanding of architectural forms, Rasmussen makes a distinction between "cavity minds" and "solid minds." Cavities, or enclosed spaces, are produced by adding to a simple construction or subtracting pieces from a bigger solid. Forms can be built in this way. The carving of caves into solid materials is one instance of architecture that emphasizes the use of voids or empty spaces. A solid-minded approach to architecture, on the other hand, may combine solids and voids to produce forms. Structures can also have solids and voids of different sizes such as building blocks and their facades containing windows and doors. Therefore, he defines architecture as "the art of playing with solids and voids."

Based on this distinction, we created three algorithms providing building and room-scale approaches. We developed a room generation algorithm for the room-scale option that allows the user to specify dimensions, windows, and doors while playing with solids and cavities. For a building-scale content generation, we have implemented two techniques: a solid-minded approach using a combination of Binary Space Partitioning and Cellular Automata algorithms and a cavity-minded approach using a constrained growth algorithm. These algorithms, which are commonly utilized in conjunction with random number generators to generate diverse game levels, were modified to incorporate user preferences and data in order to generate various levels of automation. Each algorithm offers three automation options, allowing users to either generate a 3D environment using provided data and random numbers or to define their own parameters through the interface. This approach allows users to exert creative control over mechanisms with varying levels of granularity. In all three cases, we made architectural choices to ensure coherence in the generated environment and a consistent user experience. Users have the ability to alter the produced building models using the same operations that can be applied to other assets (Figure 7). If the user does not utilize the scale operation, the height of all vertical components is established by the parameter specified by the user at the outset of the experience. As input for the algorithms, we utilized the same assets provided as primary construction objects.

Figure 7: Output of BSP Algorithm after user intervention.

3.5.1. Calculation Strategies Based on Data

The user's data are analyzed and organized into columns in order to calculate the number of rooms and minimum dimensions needed (Algorithm 1). Artifacts are then sorted into groups based on style, artist, and location, and displayed in an artifact analysis panel along with information on artifact types. The number of rooms is determined based on the user's chosen categorization criteria. For instance, if the user selects the "artist" category, the number of artists will also determine the number of rooms. Each artifact is then assigned to a specific room based on this classification. The dimensions of audio, video, and text artifact holders are predetermined, and their size in the X-axis is directly included in the overall sum. The dimensions of paintings and sculptures are obtained from the data provided, and if this information is not available, a default dimension of one meter is set on the X-axis. The sizes of labels and the space between displayed objects are fixed, and these values are also included in the total sum for each artifact. Artifacts are arranged in lists based on the date aspect, with those that do not have a specified date being placed in alphabetical order. The space between each artifact is determined based on their sizes, and this value is added to the sum along with the minimum entrance size for two parallel walls. The final step involves dividing the calculated length into two, resulting in the sum of two walls that are perpendicular to each other. These calculated lengths are then passed on to other algorithms as a parameter to define the dimensions of the rooms.

Algorithm 1
Room Number and Size Calculation

```
Parse user data into columns
Group artifacts by style, artist, and location
Define the number of rooms based on user categorization selection
Assign each artifact to a room
foreach Room do
   foreach Artifact in a room do
      if the artifact is audio, video, or text then
         Add dimension in X-axis to sum
         else
         if Dimensions are available then
            Extract the X-axis dimension from the data and add it to the sum
            Else
            Set the default dimension as one meter and add it to the sum
         end if
      end if
      Add constant label and space sizes to sum
      Divide the X-axis dimension by four and add to the sum as spacing
   end for
   Add minimum entrance size for two parallel walls (2-meters x 2) to sum
   Divide the sum by 2 to get the sum of two perpendicular walls
end for
```

3.5.2. Constrained Growth Algorithm

Using a building outline for floor plan generation allows for the establishment of boundaries for the procedural method. To ensure consistent footprints for users, we extract floor plans of existing museums from websites such as Archdaily and Divisare, resulting in the collection of 20-floor plans with varying levels of complexity in terms of space. We utilized OpenCV to extract the outlines of the floor plans and transformed them into footprints using a filling operation. These footprints served as the solid structures within which cavities would be grown. After conducting several experiments, we determined that the size of the .png files containing footprints should be 128x128 pixels in order to satisfy computation limitations. The prepared footprints, which have been formatted according to pixel and color requirements, are made available to users as options. To use the algorithm, the user first selects the desired footprint. The user has the option to specify the starting growth points by selecting a pixel from the image of the footprint, or if data is available, by selecting from among the sorting categories (style, artist, location) that determine the number of rooms. The algorithm then selects random points based on optimal distances. Alternatively, if no data is available, the user can allow the algorithm to randomly choose the number and location of the points. The starting points are arranged in the form of a square with a 1-pixel void, and 8 pixels serving as boundaries around (Algorithm 2). Following the selection of starting points, based on pixel-based search, these points begin to grow until they reach the borders of the footprint or the borders of other rooms, forming cavities within the footprint (Figure 8). Upon completion of the growth process, the corners of the containers are determined by continuously adding and comparing the positions of pixels belonging to a particular room. Based on the corners, center position, and dimensions of the wall segments are defined for the placement of 3D wall models. For each room, 3D floor tiles and their mirrored roof counterparts are placed in accordance with empty pixels and walls.

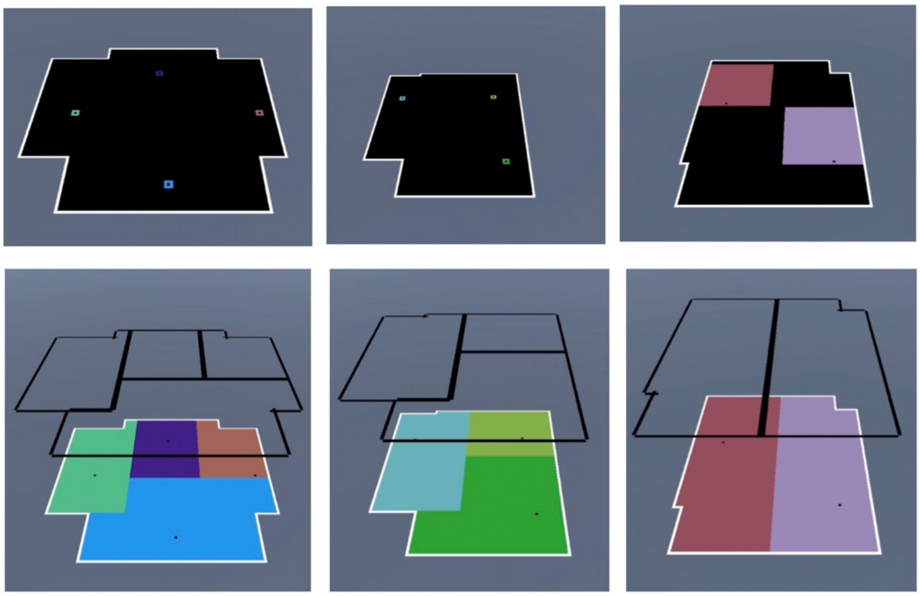

Figure 8: Example outputs of Growth Algorithm.

Algorithm 2
Constrained Growth Algorithm

```
Initialize new list cornerList
From (minx, minY) search four directions for a boundary pixel
if it is found then
    Add to the cornerList
    else
    Move
end if
Sort corners clockwise
if a room is placed, then
    Check Region
    if the region is clean, then
        Draw room boundaries
        Add a room to the room list
        else
        Terminate the Room
    end if
end if
if it is not paused, then
    Iterate through the list of rooms and find candidate walls
    while the number of growable walls > 0 do
        Grow the room
        Update walls
        Update texture
    end while
end if
```

3.5.3. Room Generation

The room generation algorithm creates a cubic room using a generic wall, roof, and floor assets as a solid foundation. In the data-based version of the algorithm, the user has the ability to select sorting options for the assets and assign them to each room based on the number and sizes of the artifacts that the room will contain. The dimensions of the room are calculated, and the initial room is scaled to fit these measurements. A button is generated for each room, allowing the user to easily spawn the room in the virtual environment. In the version of the algorithm based on user preferences, the user initially places a generic room that contains the generation algorithm. The user has the ability to manipulate the cavities and solids by defining the dimensions of the room, the number of windows, and the number of doors. The wall and floor assets used to construct the initial solid, as well as the voids with the window and door assets, are provided to the algorithm (Figure 9). Upon pressing the generate button, the floor and wall tiles are replaced based on the specified dimensions. The algorithm then alters the wall tiles to window and door tiles according to the numbers specified by the user.

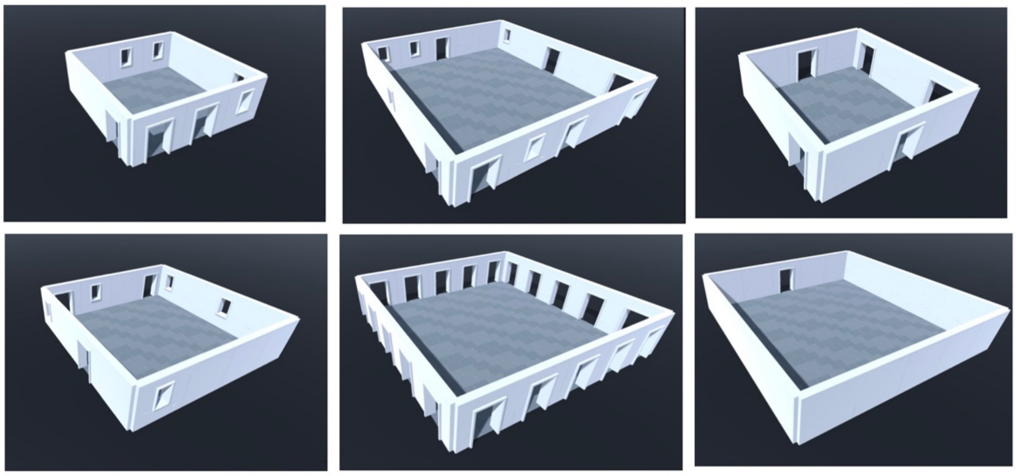

Figure 9: Example outputs of Room Generation Algorithm.

3.5.4. BSP and Cellular Automata

Cellular automata (CA) and binary space partitioning (BSP) are algorithms that can be utilized independently or in conjunction to generate layouts. BSP is a method commonly used in computer graphics to divide a 2D or 3D space into smaller subspaces or nodes. Typically, the number of subspaces in BSP is determined using a random number from a range with a seed provided for variation, and it is frequently employed to generate complex 2D dungeon patterns. This study employed BSP to create interconnected rooms and corridors, but in contrast to traditional techniques, we utilized user preferences to constrain the algorithm rather than relying on random numbers. Cellular automation is a type of mathematical system that consists of a grid of cells with a limited number of possible states. These states are determined by the states of neighboring cells, allowing for the creation of complex patterns and structures through simple rules. In video games, cellular automata are often used to generate natural-looking environments like caves and forests. In this study, we used cellular automata to create a 3D model of a generated grid based on the cell states.

BSP is a technique for dividing a space into smaller, hierarchical subspaces by iteratively applying a dividing plane. This process creates a spatial binary tree in which the leaf nodes correspond to areas of the space that can be partitioned into rooms. The divisions may be placed arbitrarily, resulting in a variety of sizes and shapes for the subspaces. Adjacent relationships are established between the resulting rooms to enable navigation within the partitioned space. In this study, the BSP algorithm offers data-driven, user-driven, and random generation. In the data-driven version, the algorithm uses data analysis to determine the number and dimensions of the rooms, along with other variables that are generated based on a specified seed. In the absence of data, the algorithm randomly generates all of the necessary parameters using the defined seed. In the user-driven version, the user has the ability to specify constraints on the dimensions of corridors and rooms, the dimensions of the overall space, and the number of rooms, enabling them to exert a degree of control over the generated layout (Figure 10).

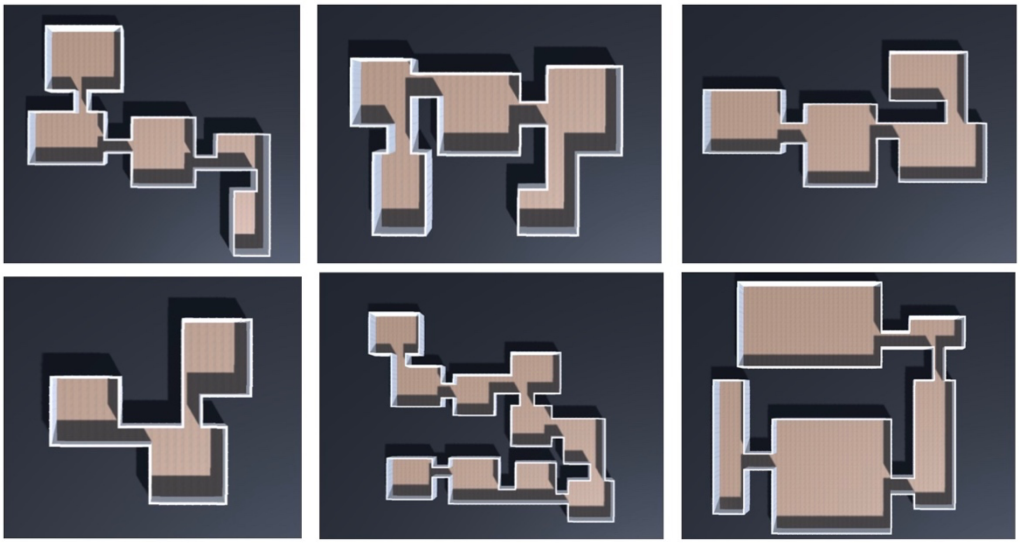

Figure 10: Example outputs of BSP Algorithm.

Using BSP, we generated a layout by first defining the initial boundary, referred to as the footprint (Algorithm 3). The dimensions of the footprint, which can be adjusted based on the user's preferences, influence the overall placement of the layout. For instance, the user can manipulate the width and depth ratio to generate side-by-side blocks or more compact structures. To proceed with the layout generation, the initial boundary, also known as the footprint, is divided into smaller spaces based on the specified number and dimensions of rooms. This division is carried out using the BSP technique, which involves the use of a seed value to generate a random sequence of numbers. These numbers are then used to randomly determine the position and orientation of the partitions, resulting in a layout with a high degree of variability. The seed value is used to initiate the generation of a sequence of random values through the use of a random number generator. This sequence is then used to determine the position and orientation of the partitioning divisions, which are based on the specified room and corridor dimensions and the seed value. By keeping the seed value constant, it is possible to recreate the same layout multiple times. The partitioning process continues until the desired number of rooms is reached, as defined by the user.

The tree structure produced during the layout generation process represents the different subspaces within the layout. To create the final layout, the tree is traversed and at each node, a room is included in the layout if possible. The algorithm then tries to place corridors in the four cardinal directions if there is enough space. If not, the process is stopped, and the division is restarted. Each node in the tree represents a subspace within the layout.

Algorithm 3
Binary Space Partitioning and Cellular Automata

```
Initialize the layout with the given footprint dimensions
Use the seed value as the input to a random number generator
while layout.num_nodes < user.num.rooms do
    Select a random location and orientation for the division
    Divide the layout into smaller subspaces
end while
Traverse the tree structure of the layout
Recursively visit each node in the tree structure of the layout
if the node can create a room, then
    Add it to the layout
    Try to place corridors in all four cardinal directions
    else return
end if
if layout.num_nodes = user.num.rooms, then
    Iterate over the cell states and place 3D models
    else return
end if
```

The BSP algorithm works with cells, making it an ideal candidate for integration with Cellular Automata (CA) for the generation of rule-based 3D structures. In order to construct the 3D model of the data structure generated using BSP, we defined a set of states for the cells. Initially, all cells are in an empty state. As rooms are placed within the spatial binary tree, the cells change their states to reflect the presence of walls, corners, floors, doors, or windows. In the process of constructing the 3D model of the generated data structure, wall and roof tiles do not require rotation, while the wall, corner wall, and door tiles have different states that involve the application of rotational operations. The rules are applied, and 3D assets are placed accordingly. Instead of creating a separate state for the roof, we assigned the responsibility of generating roof tiles to cells in the "floor" state, which are able to duplicate the tiles based on the defined height.

CHAPTER 4

EVALUATION

4.1. Ethics

A document covering the study's objectives, methodology, and instruments was submitted to the Middle East Technical University Human Subjects Ethics Committee, and Ethical Approval of Research is given by the committee in April 2022. Prior to the process, each participant was given a consent form that included a brief explanation of the study's aims and objectives, data collection methods, anonymity, the assessment of their data, the procedure, and potential risks associated with VR platforms, such as motion sickness and nausea. Throughout all the sessions, participants were informed that they might leave at any moment if they felt uncomfortable or disturbed. The research participants received no compensation, and their participation was entirely voluntary.

4.2. Participants

According to Sandelowski [133], the determination of sufficient sample size in qualitative research is closely tied to the depth of the material, the sampling procedure used, and the research product. To determine the optimal sample size for quantitative usability research, Faulkner performed experiments with various sample sizes. The results of the research indicate that twenty participants are sufficient to achieve a confidence level of 95% and offer an effective sample size for detecting current usability issues. Thirty participants between the ages of 20 and 35, with a mean age of 24.67 ± 4.13 years were recruited considering the complexity of the approaches applied and the volume of information that would be generated. Recruited respondents with diverse backgrounds were selected for the study. According to self-reported statements, each participant's eyesight was normal or corrected to normal.

4.3. Procedure

According to Sukamolson [134], quantitative techniques are more appropriate for examining causality and the effects produced, whereas qualitative methods are more suitable for assessing the importance of specific factors or circumstances. Since our research questions in this study require comparing versions based on their causality and meaning, as well as analyzing the preferences in detail, we employed a mixed-method approach combining quantitative and qualitative methodologies. To get a better insight into the differences between versions, the framework's use, and the preferences of the participants, together with the reasoning behind them, a five-stage process, including quantitative surveys using frequently used questionnaires and exploratory interviews with a semi-structured format, was devised as part of the mixed-method approach.

Prior to the version test, respondents were asked to complete the Gamer Motivation Profile [135], Immersive Tendencies (ITQ) [136], and Tool Competency questionnaires to assess their technological background and personal preferences. For the version test, we developed a two-step approach where users first provided an identical dataset and digital collection to eliminate results stemming from the size or quality of the assets, and then they were asked to assess the application's specific features, such as lighting configurations and procedural generation techniques. In the second part, participants used their personal collections. After exposure to all three versions, the qualitative assessment of the framework required participants to evaluate the system via the System Usability Scale (SUS) [137], the Presence Questionnaire (PQ) [138], and the Technology Acceptance Model (TAM) [139] questionnaires together with the surveys corresponding to lighting options procedural generation, and interaction preferences generated for this study. In the last stage, brief interviews with a semi-structured format were conducted. Each session lasted around one hour, excluding the unstructured part of the interviews.

4.4. Data Collection Methods

4.4.1. Semi-structured interview

Following the session, semi-structured interviews were conducted as part of our mixed methodology for gathering qualitative data. First, we outlined the main themes to be investigated and developed a guide with 11 questions. The themes gathered around general impressions, suggestions, possible use cases for the framework, their possible intention to use, and the affordances of the algorithms are provided for content generation and data analysis. During the unstructured part, we tried to identify the more specific reasons that may affect the quantitative results and occurrences that might offer us insightful information.

4.4.2. Questionnaires

The System Usability Scale was constructed by John Brooke in 1986 to evaluate the usability of a system for broad purposes which are frequently used to compare and assess the success of outputs. The self-report scale is intended to assess perceived ease-of-use and learnability using a Likert Scale in which questions are rated from 1 to 5, starting with strong disagreement to strong agreement. The comprised 10 questions consist of 5 negative and 5 positive statements. The calculation method based on the data gathered from participants generates a score between 0 and 100.

Although there are numerous definitions of "presence," it is most commonly defined as the "feeling of being there," which has been a critical concept, especially for immersive environments. According to Cummings and Bailenson [77], the level of presence affects users' engagement time, interaction capacity, and cognitive load. Accepted as one of the measures of the system's effectiveness, the ability to give high degrees of presence is contingent on the system encountering several elements that influence the amount of users' sensation of presence. To evaluate the presence level according to its requirements, the Presence Questionnaire was first developed by Witmer et al. [138]. The subsections that are constructed are related to the quality of the various inputs and experiences provided. In this study, we used subsections that are applicable to all developed versions. Similar to other questionnaires, PQ is also rated on a 7-point Likert scale.

Since its initial publication in the literature, the Technology Acceptance Model has been one of the most widely used models of technology acceptance. To ascertain the degree of acceptance of the technology, particularly in the early stages of a system, based on the user's attitude toward the technology, it includes two primary factors: "perceived ease of use (PEU)" and "perceived usefulness (PU)." A revised TAM questionnaire used in this study [140] consists of ten items divided into two groups and rated on a 7-point Likert scale, starting from strong agreement to strong disagreement. While the first six questions are used to determine perceived usefulness, they evaluate the required effort from users and the ease of use which positively increases users' attitudes. The latter four are used to compute perceived ease of use, which is related to the intention to use based on the positive effects that can be created by the new product.

The results of the SUS, TAM, and PQ questionnaires are based on the ratings of the participants, which correspond to their individual experiences with the system, which can be affected by their backgrounds and personal behaviors. To further analyze criteria that may affect the results of the versions, we conducted two questionnaires before the test of the system to analyze participants' familiarity with the hardware and methods and also their certain tendencies. To measure their previous experiences with VR and MR technologies, we directly asked them to assess their tool competence level on a Likert scale rated between 1 and 7. On the other hand, for the PC version, we employed a different approach. The interaction and navigation methods that we used in the PC version have a high degree of similarity to video games. For example, for navigation, we use the keyboard and mouse interactions with the inputs that are commonly used in video games. We also provided four camera options, which are well-known for video games but are absent in VR and MR experiences.

Drawing from these relationships, we employed a well-known questionnaire created by Quantic Foundry to identify participants' degrees of video game experience in the study. Based on research into gaming trends and several factors, the team at Quantic Foundry devised a set of six questions that constitute the Gamer Motivation Profile. They concluded that there are four distinct groups of gamers, with the least experienced being non-gamers and the most experienced being hard-core gamers. The questions are based on the respondents' own assessments of themselves, such as how often they play games, how skilled they feel they are, and what their favorite games of the moment and all time are.

To measure the well-being of the participants before the versions, their attitudes towards digital mediums, and the tendencies that can influence experiences of exposure to a digital environment, we provided the Immersive Tendency Questionnaire examines the statistical data to evaluate how people respond to digital environments based on their personal attributes. The questionnaire consists of 18 items and four subsections on involvement, focus, emotions, and willingness to play video games, to provide a credible and reasonable evaluation of the correlation between the cognitive variables of individuals and the provided digital setting.

In addition to questionnaires that are widely used in the literature, to find answers to our research questions that are specific to the framework that we developed, five additional questionnaires were constructed. The first one was to measure the tool competence regarding VR and MR versions, which was previously explained. We constructed two interaction preferences questionnaires to identify the personal preferences for hand interaction and controllers in VR and MR environments and interaction with asset types in all three environments. Within the framework, five types of assets (text, image, video, 3D models, audio) and nine different formats (.txt, .csv, .jpeg, .jpg .png, .mp4, .fbx, .obj, .mp3) are acceptable. As an interactive medium, in addition to the 3D artifact holders designed, we provided a 2D ArtCanvas view. The constructed questionnaire is to answer one of the research questions about understanding better ways to convey information in different formats and the effects of different mediums, which can provide insights for further improvements. During the experiences in virtual environments, tasks and roles performed via user lighting preferences may change. In this study, we provided control over lighting temperature, and to test the preferences, we grouped the lighting temperatures into three groups: cold, neutral, and warm, and roles into two groups: curator/designer and visitor. To support the design and curation processes we integrated three automated generation algorithms whose automation level depends on the users' preferences. One of the aims of this study is to investigate the relationship between comprehensibility, autonomy level, and the design outcomes of the algorithms. Therefore, in the final questionnaire, respondents were provided questions related to the factors that we focus on for three algorithms with their semi- and fully-automated versions.

CHAPTER 5

RESULTS

This chapter provides the statistical analysis of the quantitative data collected through the evaluation procedure with the participation of 30 respondents. All participants tested the PC version of the framework using a MacBook M1 Pro 13". For the VR and MR versions, Oculus Quest 2 is used. The HMD and PC's built-in speakers were used for audio. The responses to open-ended questions were analyzed using the MAXQDA analysis tool (2022). The collected quantitative data were analyzed via the software program JASP (2022 V.0.16.4). To test the validity of questionnaires that use Likert scales, calculating Cronbach's alpha values has become a common practice. Therefore, in addition to the calculated mean and standard deviation results, to determine the reliability and internal consistency of the results, Cronbach's alpha (α) values of the subsections if they are available and the overall results were computed. Cronbach's alpha tests produce a number between 0 and 1, and the interpretation of the number can be seen in Table 1.

Table 1: Interpretation of Cronbach's Alpha (α) values [112].

Cronbach's α	Cronbach's α Comments
$\alpha \geq 0.9$	Outstanding
$0.7 \leq \alpha < 0.9$	Good
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Weak
$\alpha \leq 0.4$	Unacceptable

5.1. Semi-structured Interview

Within the first two questions of the interview, participants were asked to elaborate on their overall impressions of the framework and their understanding of the intended utilization. The frequency distribution of words used often to describe the different versions of the framework and its applications is shown in Figure 11, Figure 12, and Figure 13.

Figure 11: Frequency Mapping of most used words by participants to describe the VR version of the framework and possible employment areas. Produced with MAXQDA.

Figure 12: Frequency Mapping of most used words by participants to describe the MR version of the framework and possible employment areas. Produced with MAXQDA.

Figure 13: Frequency Mapping of most used words by participants to describe the PC version of the framework and possible employment areas. Produced with MAXQDA.

5.2. Interaction Preferences

To assess hand interaction and controller preferences, participants in the study were asked to select the one that they felt most comfortable with in the VR and MR versions of the framework. The results of this evaluation, which are depicted in Figure 14, reveal the users' preferences for interaction.

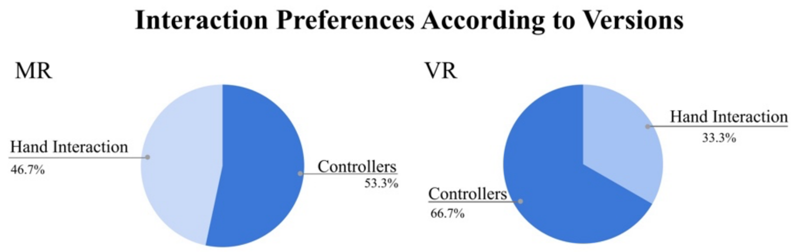

Figure 14: Hand Interaction and Controller preferences of participants for VR and MR environments.

Furthermore, the subjects were asked to select their preferred medium for interacting with different types of assets, as shown in Figure 15. These results provide insight into the most effective methods of interaction and the preferred mediums for interacting with different types of assets.

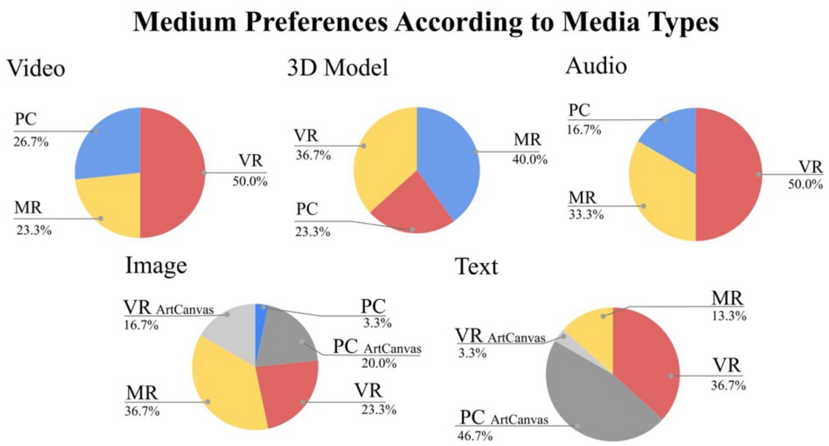

Figure 15: Interaction preferences of participants with different asset types regarding interactive mediums.

5.3. Lighting Temperature Preferences

The temperature range provided was grouped into three parts: cold, neutral, and warm. Figure 16 demonstrates users' lighting preferences in PC and VR environments regarding different roles. The MR version is not included since the virtual lighting is not provided by Oculus Quest 2 for MR environments.

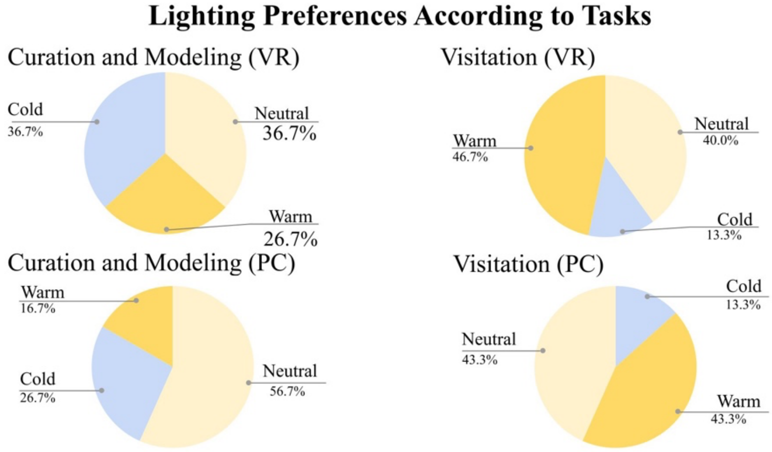

Figure 16: Lighting preferences of participants for different modes and immersive environments.

5.4. Procedural Generation Algorithms

We identified four different criteria to evaluate the algorithms that support architectural design practices based on user preferences: design outcome, comprehensibility, perceived control, and ease of use. For the versions based on data, we eliminated the perceived control and ease of use since they are irrelevant to the automated versions. Table 2 shows the mean scores of the algorithms based on user preferences together with the number of options provided to users, and Table 3 provides results for the generation based on data.

Table 2: Mean and standard deviation results of the questionnaire on a 1 to 5 scale for procedural generation based on user preferences.

	Growth Algorithm	Binary Space Partitioning and Cellular Automata	Room Generation
Number of Options	3	7	4
Perceived Control	3.56 ± 1.04	3.76 ± 0.97	4.03 ± 0.80
Ease of Use	3.90 ± 0.75	3.70 ± 0.98	4.00 ± 0.78
Comprehensibility	4.00 ± 0.81	3.66 ± 0.92	4.00 ± 0.87
Design Outcome	3.54 ± 0.97	3.43 ± 0.89	4.03 ± 0.92

Table 3: Mean and standard deviation results of the questionnaire on a 1 to 5 scale for procedural generation based on data.

	Growth Algorithm	Binary Space Partitioning and Cellular Automata	Room Generation
Design Outcome	3.23 ± 0.89	3.90 ± 0.75	3.40 ± 0.85
Comprehensibility	3.66 ± 0.71	2.86 ± 0.84	3.30 ± 0.83

The results show that the room generation algorithm based on user preferences has the highest results across all sections. The combination of BSP and Cellular Automata algorithm based on data has the best design outcome even though its comprehensibility is lower than that of other algorithms (Figure 17).

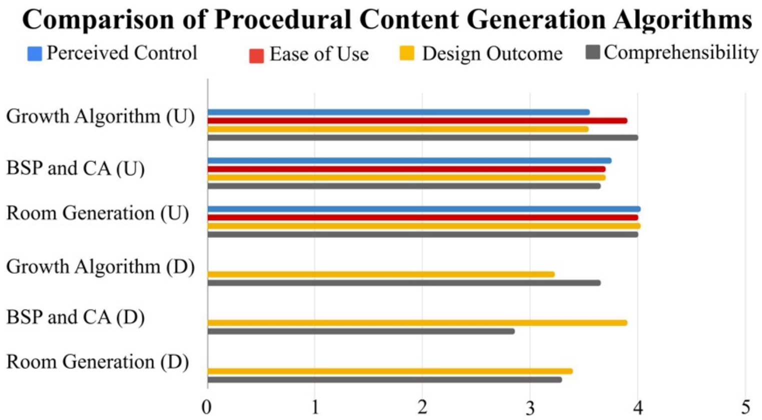

Figure 17: Comparison of PCG algorithms based on mean scores.

5.5. System Usability Scale

There are no subscales on the SUS questionnaire, however, the raw responses to the negative and positive statements are subjected to several different operations to produce a normalized total rank, which ranges from 45 for the lowest score to 100 for the highest score. A grading table is offered [137] and is included in Table 4 to help explain the SUS scores. To describe a system's usability, it comprises ratings, descriptors, and acceptance for various percentages and grades. Cronbach's alpha values were calculated for each version to assess the validity of the SUS findings. The results were verified upon examination of Cronbach's alpha values [141] of the SUS scores. Cronbach's alpha values are shown in Table 5, while mean and standard deviation statistics are shown in Table 6, as well as a box plot in Figure 18.

Table 4: SUS Scoring Table [108].

Grade	SUS	Percentile Range	Adjective	Acceptability
A+	84.1-100	96-100	Best Imaginable	Acceptable
A	80.8-84.0	90-95	Excellent	Acceptable
A-	78.9-80.7	85-89		Acceptable
B+	77.2-78.8	80-84	Good	Acceptable
B	74.1-77.1	70-79		Acceptable
B-	72.6-74.0	65-69		Acceptable
C+	71.1-72.5	60-64	OK	Acceptable
C	65.0-71.0	41-59		Marginal
C-	62.7-64.9	35-40		Marginal
D	51.7-62.6	15-34	Poor	Marginal
F	25.1-51.6	2-14		Not Acceptable
F	0-25	0-1.9	Worst Imaginable	Not Acceptable

Table 5: Cronbach's Alpha values of System Usability Scale.

Version	PC	VR	MR
Cronbach's α	0.653	0.874	0.670

Table 6: Mean and Standard Deviation results of System Usability Scale.

Version	PC	VR	MR
Mean	79.91 ± 10.89	70.00 ± 14.03	77.51 ± 12.99

The SUS scores are found acceptable, according to Cronbach's alpha values (PC (0.653 > 0.5), VR (0.874 > 0.5), and MR (0.670 > 0.5). The scoring table reveals that all three versions of the framework are graded "B" and have "good" usability levels, reflecting high rates of system usability. On the other hand, the PC version has the highest average (79.91%) and the highest consistency levels, while the VR version has the lowest usability (70.00%). However, the MR version's usability rating (77.51%) is rather comparable to the PC version.

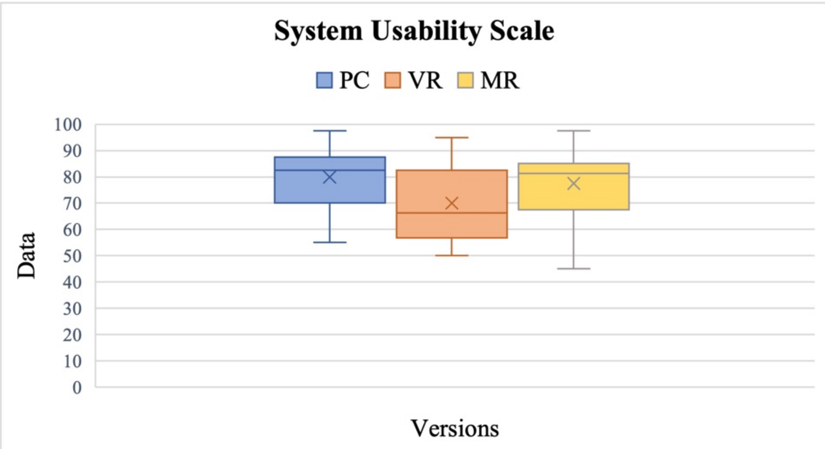

Figure 18: Comparative results of the System Usability Scale.

We carried out linear regression analyses between tool competency levels and the individual participant ratings and computed the correlation coefficients to examine the individual differences that could influence the SUS outcomes. Figures 19, 20, and 21 show the outcomes of the linear regression, while Table 7 displays correlation coefficients between participants' tool competence levels for related technologies and their SUS ratings for different versions. The strength and presence of relationships between data variables and the direction of a linear relationship, which may be positive or negative, are evaluated using correlation coefficients. In this investigation, the Pearson correlation coefficient was computed. It has a range of -1 to 1, with 0 denoting no association. Typically, a threshold of -0.5 for negative correlation and 0.5 for positive correlation is necessary to demonstrate the presence of a correlation between variables. Table 7 shows a positive correlation between SUS ratings and tool competency.

Table 7: Correlation Coefficients between SUS scores and tool competence levels.

	PC	VR	MR
Correlation Coefficients	0.66	0.73	0.73

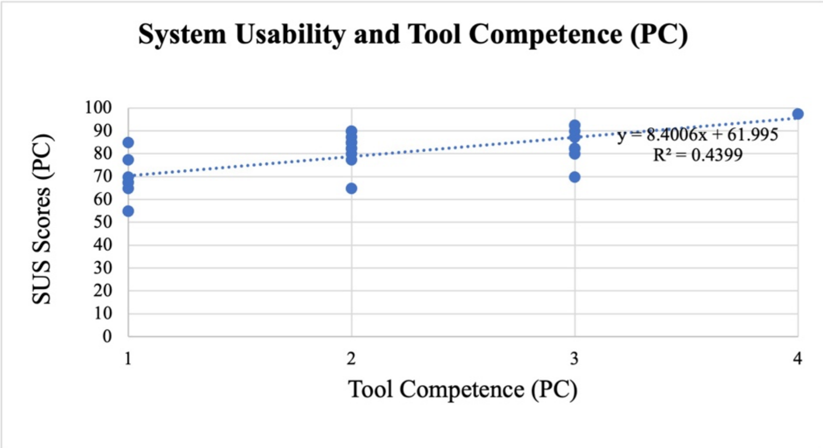

Figure 19: Linear Regression results between participants' tool competence levels of PC and SUS scores of the PC version.

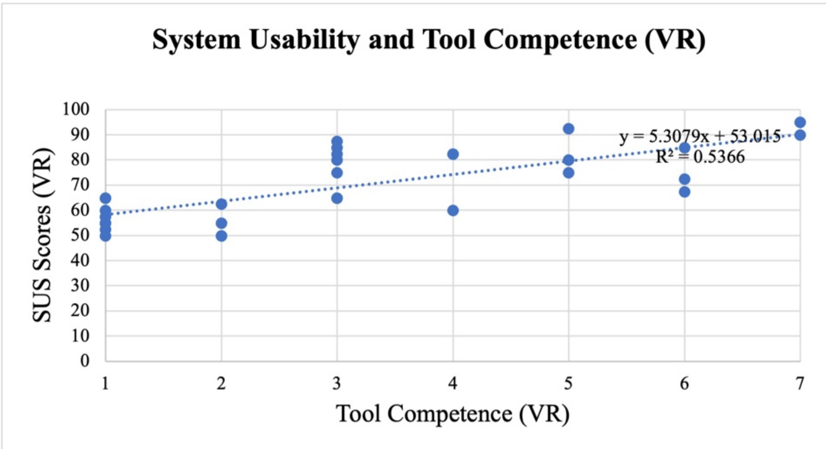

Figure 20: Linear Regression results between participants' tool competence levels of VR and SUS scores of the VR version.

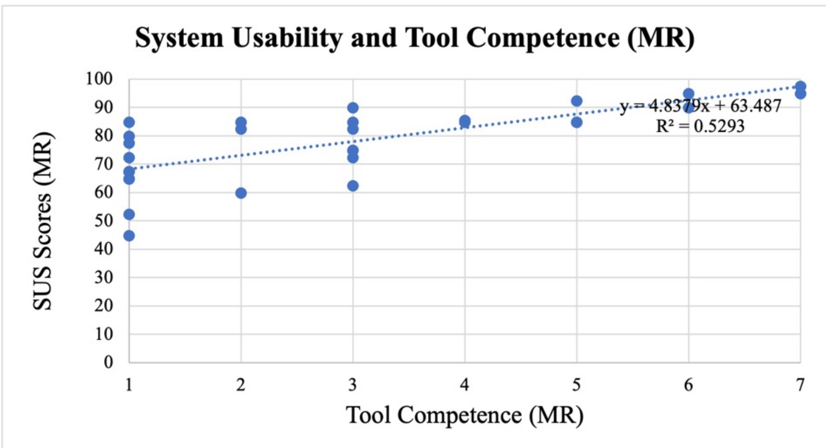

Figure 21: Linear Regression results between participants' tool competence levels of MR and SUS scores of the MR version.

5.6. Technology Acceptance Model

Results of the analysis of the TAM questionnaire and its subsections, which each include 10 questions, are shown below. Only numerical analyses were carried out due to the lack of a scoring table for the interpretation of the scores. Results for reliability are shown in Table 8, and results for the mean and standard deviation of the model and its subsections are given in Table 9.

Table 8: Cronbach's Alpha values of Technology Acceptance Model.

Version	PC	VR	MR
Cronbach's α	0.640	0.857	0.848

Table 9: Mean and standard deviation results of the Technology Acceptance Model.

Version	PC	VR	MR
Perceived Usefulness	5.63 ± 1.05	5.47 ± 1.22	5.5 ± 1.24
Ease of Use	5.54 ± 1.05	4.88 ±1.13	5.15 ± 1.41
Total Mean	5.60 ± 1.05	5.23 ± 1.22	5.29 ± 1.35

Cronbach's alpha (α) values greater than 0.5 confirm that the obtained data is reliable (PC (0.640 > 0.5), VR (0.857 > 0.5), and MR (0.848 > 0.5)). As Table 9 presents in terms of total mean, PU, and PEU scores, the PC version provides a better technology acceptance level. According to the comparative analysis presented in Figure 22 regarding all scores, while responses to PC and MR present more consistent results, the scores given to the VR version are more diverse. Besides Table 9, Figure 23 provides a comparative analysis regarding subsections.

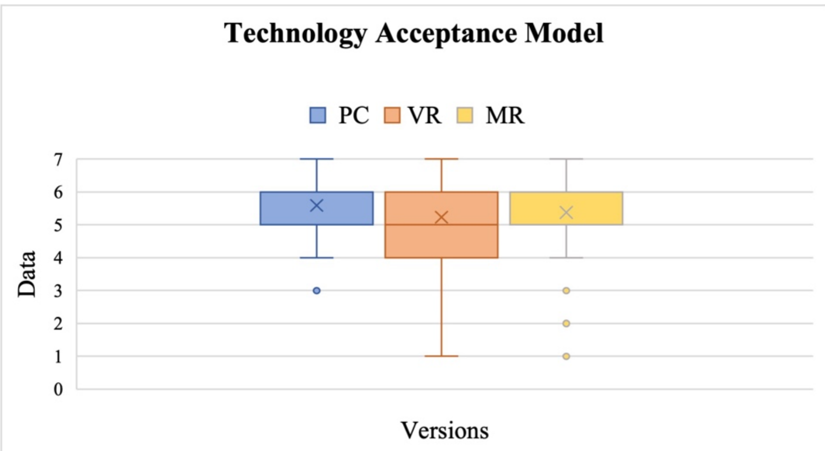

Figure 22: Comparative results of the Technology Acceptance Model.

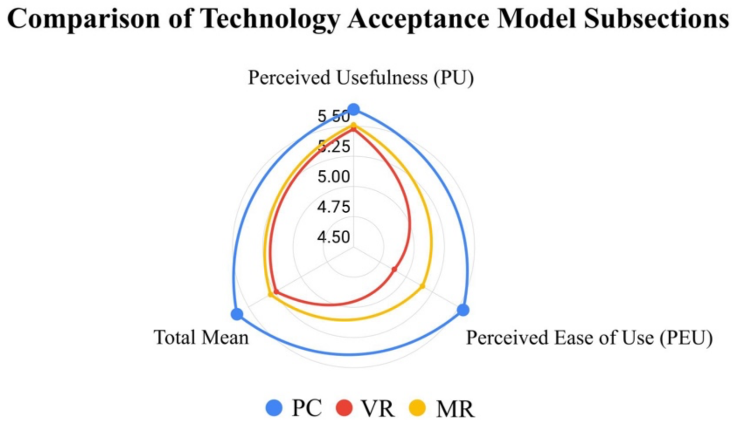

Figure 23: Comparative results of Technology Acceptance Model Subsections.

Similar to SUS scores, we conducted a linear regression analysis between individual tool competence levels and TAM scores. Table 10 provides correlation coefficients, while Figures 24, 25, and 26 demonstrate the individual results on scatterplot diagrams for all versions.

Table 10: Correlation Coefficients between tool competence levels and average TAM scores.

	PC	VR	MR
Correlation Coefficients	0,79	0,70	0,53

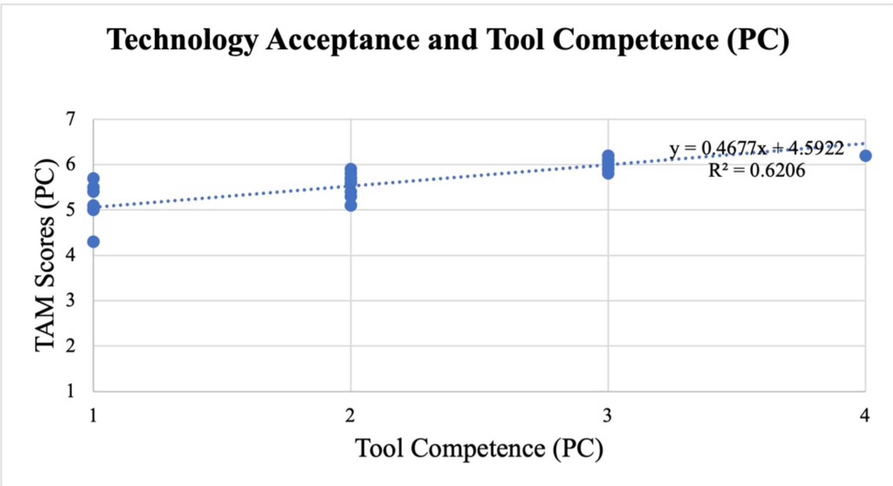

Figure 24: Linear Regression results between participants' tool competence levels of MR and TAM scores of the PC version.

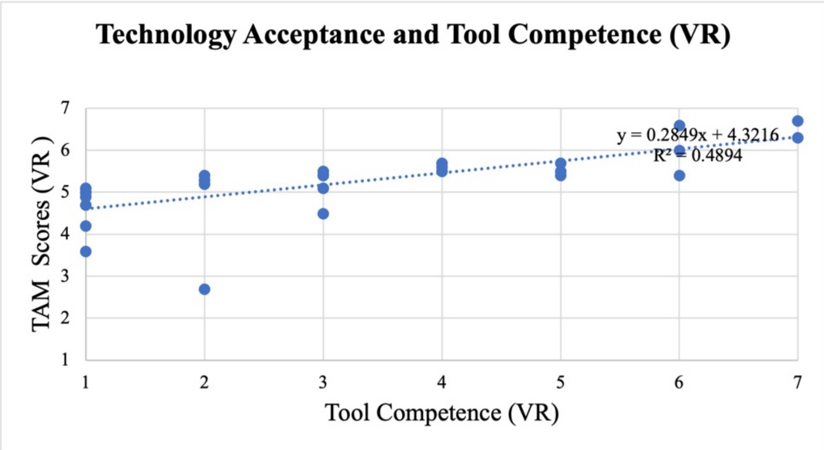

Figure 25: Linear Regression results between participants' tool competence levels of VR and TAM scores of the VR version.

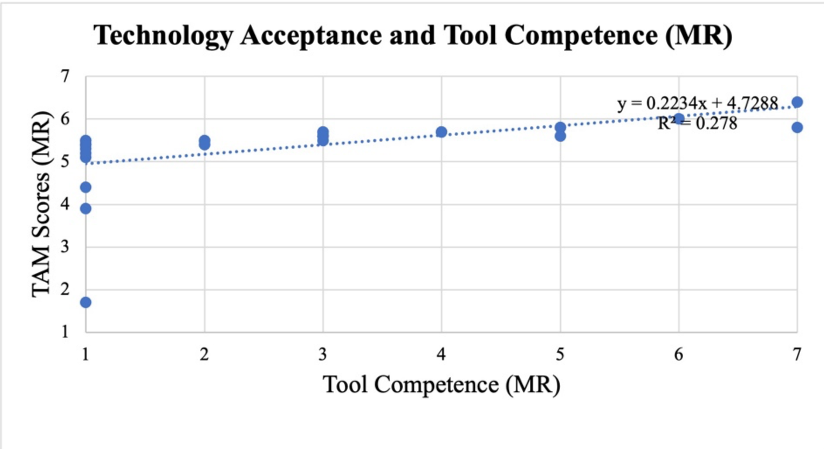

Figure 26: Linear Regression results between participants' tool competence levels of MR and TAM scores of the MR version.

5.7. Presence Questionnaire

The Presence Questionnaire was used to measure participants' level of presence during exposure to Framework. It is divided into several parts that each reflect a distinct aspect of the virtual world. These sections include realism, which evaluates the virtual environment's plausibility, authenticity, and genuineness, the possibility to act, which assesses an individual's ability to interact with and influence the virtual environment; the quality of the interface, which measures the usability and effectiveness of the interface between the user and the virtual environment; and the possibility to examine, which assesses an individual's ability to explore and examine the virtual environment and their level of comfort during navigation, and self-evaluation of performance, which requires respondents to evaluate their skill level and capacity to engage in virtual interactions. The PQ assesses the feeling of presence in a virtual environment based on these different characteristics, and the overall system performance and scores of each section are calculated separately. The internal consistency values are presented in Table 11, and the calculated scores for each version are shown in Table 12, comparative results are given in Figures 27 and 28.

Table 11: Cronbach's Alpha values of Presence Questionnaire.

Version	PC	VR	MR
Cronbach's α	0.67	0.55	0.56

Table 12: Mean and standard deviation results of PQ.

Version	PC	VR	MR
Realism	5.26 ± 1.2	5.02 ±1.31	5.02 ±1.45
Possibility to Act	5.40 ± 1.15	5.25 ± 1.46	4.93 ± 1.37
Quality of Interface	4.37 ± 1.52	4.33 ± 1.56	4.93 ± 1.49
Self-evaluation of Performance	5.53 ± 0.92	5.38 ± 1.09	4.78 ± 1.43
Total Mean	5.14 ± 1.27	4.97 ± 1.46	4.93 ± 1.44

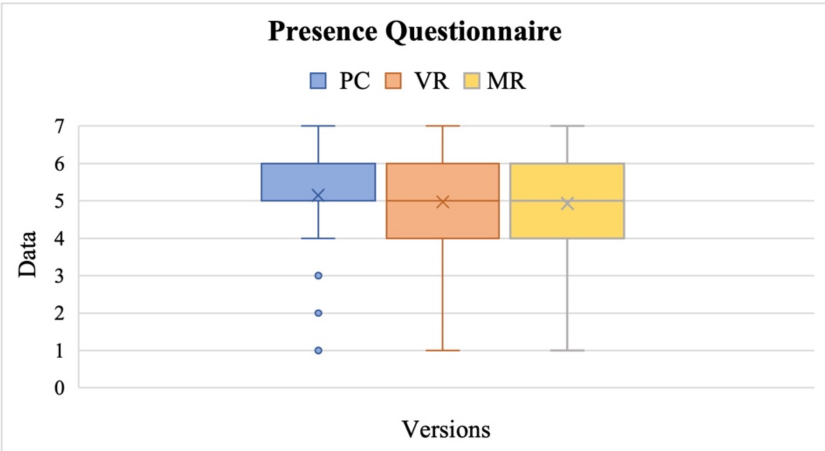

Figure 27: Comparative results of Presence Questionnaire.

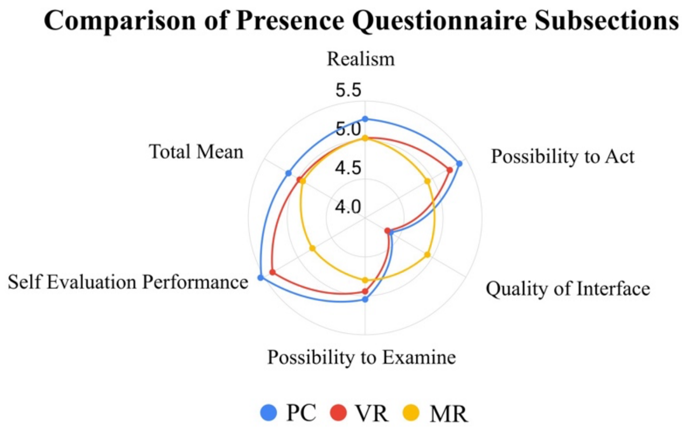

Figure 28: Comparative results of Presence Questionnaire subsections and total scores.

We conducted a linear regression analysis between individual tool competence levels and presence scores. Table 13 presents correlation results and Figures 29, 30, and 31 demonstrate the individual results on scatterplot diagrams for all versions.

Table 13: Correlation Coefficients between tool competence levels and average Presence scores.

	PC	VR	MR
Correlation Coefficients	0.67	0.55	0.56

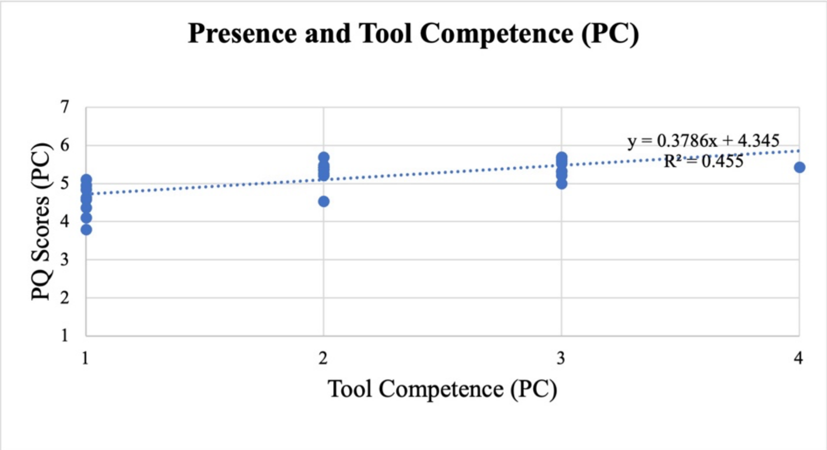

Figure 29: Linear Regression results between participants' tool competence levels of PC and scores of the PQ for the PC version.

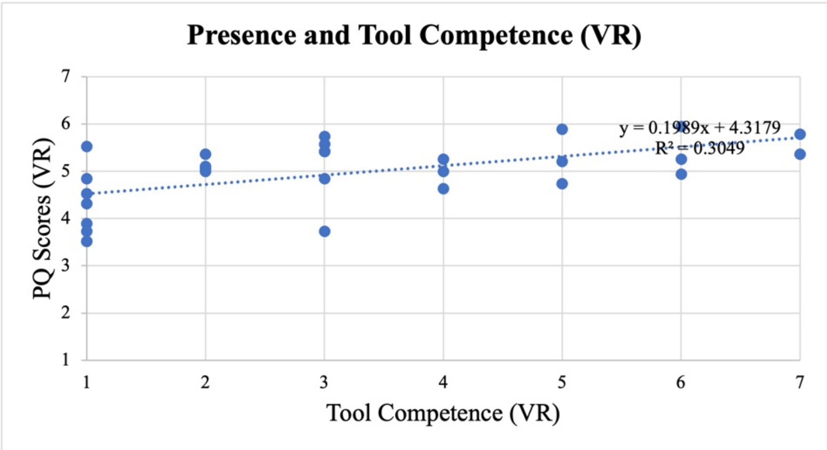

Figure 30: Linear Regression results between participants' tool competence levels of VR and scores of the PQ for the VR version.

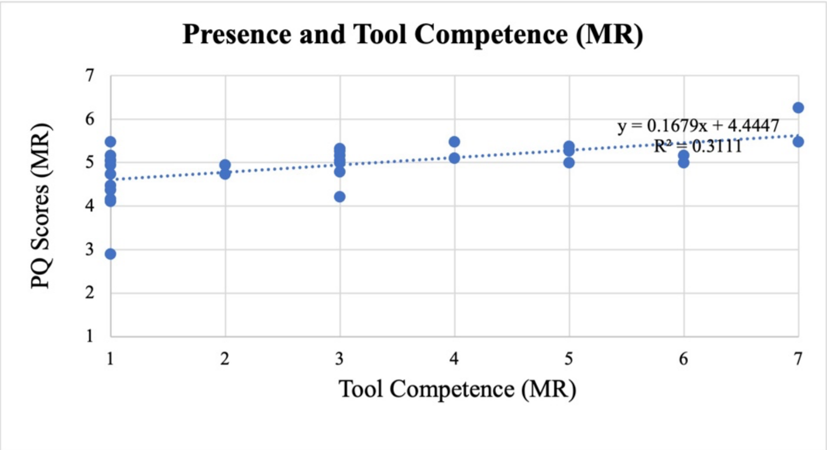

Figure 31: Linear Regression results between participants' tool competence levels of MR and scores of the PQ for the MR version.

CHAPTER 6

DISCUSSION

Heterotopias are enigmatic realms that bridge diverse systems through the flow of knowledge and are marked by the coexistence of multiple layers. Inspired by the features of discursive heterotopias, the framework proposed in this study is intended to be adaptable and modular, suitable for a range of contexts in the creation of digital habitats that foster discourse. Owing to the multifaceted nature of heterotopias, a range of evaluation methods were employed to assess the suitability of the approaches in relation to the objectives.

6.1. User Experience and Individual Preferences

To evaluate the framework using individual archives, some participants compiled a set of assets specifically for the sessions, while others preferred to utilize existing materials from their online or offline databases. While the pre-assembled dataset afforded us valuable insights into the technical aspects of the framework, its capacity to create distinctive heterotopias was most apparent when personal experiences and archives were employed, demonstrating the framework's versatility across a range of contexts. The "operating table" approach, which enables the co-location of multimedia elements, has presented a wealth of possibilities for participants. For instance, participants often chose to incorporate their own photographs, videos, notes, and screenshots, mirroring the accumulative nature of heterotopias with regard to time and elements. They crafted various rooms using "grids of specification" based on their own categorizations, resulting in multi-layered experiences closely tied to "self-reflection" and "self-formation." The framework's provision of individual archives and spatial layers allowed users to produce a "world within worlds."

[P.17] "I considered the experience as walking inside my brain and organizing it, so it could work. Also, the framework can be extended via deep learning algorithms for further customization and guidance."

Through the incorporation of professional resources based on "surfaces of emergence," individuals have fostered connections and experiences via embodiment. For example, design professionals have employed models, sketches, notes, and videos of production to craft narrative exhibitions. These exhibitions, which offer in-situ demonstrations and hands-on opportunities, allow attendees to experience "aesthetic becoming."

[P.22] “I think most of the design tools that we used are like trucks; this application was like a sports car.”

[P.04] “I can easily use this tool for my interior design practices, and I especially found the mixed reality version very useful.”

Participants with medical backgrounds placed anatomical models and texts, creating a gamified environment where they could manipulate the parts of the model with hand interaction. Additionally, two participants from computer sciences added new features with dynamic models via scripts embedded in 3D models based on OOP using the adaptability of the framework. The semi-structured interview aimed to explore the reasons behind the questionnaire results and the personal opinions of the participants regarding the versions of the framework. It also examined their perceptions of potential use cases for the framework. Open-ended questions were used to investigate the interpretation of the framework from the users’ perspective. Analysis of the responses to the open-ended question about the different versions of the framework, based on frequency mapping, showed that different technologies resulted in various cases. For example, while for the PC version “game,” “creative,” “fun,” and “art,” words were mostly used for the VR version “experimental,” “design,” “fun,” “architecture,” “visualization,” and “inclusive” were the most used words to describe On the other hand, MR version frequently produced “interior-design,” “prototype,” “interaction,” and “transformation.” Comparisons between the mappings indicate that MR and VR technologies can produce more comprehensive and multilayered experiences being able to provide embodied cognition. In addition to definitions, most participants provided comments based on their experiences and interpretations.

[P.02] “I would prefer to use this tool when I teach my students geography and history.”

[P.25] “We can use this tool for designing, displaying, and teaching the systems in our mechanical engineering studies.”

The wide range of cases presented by the participants suggests that the framework can be utilized in a variety of contexts. The framework’s dynamic autonomy layers and focus on self-formation based on heterotopias provided users with a flexible design space, allowing them to take on the role of “focal points of resistance” and develop unique, unstructured use cases.

Heterotopia encompasses a complex set of relationships, including the user experience which is shaped by various elements such as hardware and navigation. The participants noted that different technologies and modes of interaction are better suited for specific types of discourse. The user’s preferences for environmental factors such as lighting and scale may also vary based on their actions. The multimedia elements in the discursive space were presented using multiple representation methods. The utilization of virtual reality, mixed reality, and personal computer environments for the presentation of a range of media, including images, audio, video, text, and 3D models, has been a topic of interest. However, the suitability of a specific media type for a particular technology may depend on the user’s objectives and needs, as well as the context in which the technology is being used. Research has demonstrated that VR can provide a highly immersive and stimulating experience, allowing users to fully immerse themselves in a virtual world and interact with diverse media and virtual elements. In contrast, MR enables users to view and interact with digital media within the context of their real-world surroundings. The selection of the appropriate technology for different media types is ultimately dependent on the specific goals and requirements of the user and the context in which the technology is being utilized.

User preferences for the setting in which they engage with various forms of media vary. For example, when interacting with 3D models, users have been found to prefer VR and MR environments, citing more accurate scale perception in relation to surroundings and a more impressive experience in these environments. There has been a preference among most users for the display of videos and images on a human scale, though some variation in the preferred environment has been observed. The presence of physical objects in the MR environment has been identified as a source of distraction, leading to a preference among the majority of users for the VR environment for video content due to the requirement for sustained attention. The pairing of an entirely synthetic world with sounds in the VR environment has been found to be more compelling by most respondents for audio content. For text interactions, the most conventional view, ArtCanvas, has been preferred by the majority of users. Therefore, the prevalent media format of discourse can impact users' technology preferences.

The use of hand gestures as a means of performing tasks and manipulating objects has been shown to offer a convenient and intuitive method of interaction with digital materials. Hand gestures can be particularly useful for navigating and interacting with virtual objects and surroundings. The data collected throughout this study implies that the usability of hand gestures may vary depending on the specific context, adequate training is required, the visibility of the user's hands and the accuracy and responsiveness of the hardware to ensure their effective use. Also, the intuitiveness of the hand gestures is subject to discussion, which depends on the complexity of the gestures and the experience level of the users. Using hand gestures as a means of interaction with digital media was investigated in this study through the tracking of hand gestures using built-in cameras on a headset. Users used controllers and hand tracking during experiences to perform selection, release, manipulation, and teleportation. It was found that the hand interaction has some overlap with traditional forms of a command language, requiring users to remember specific gestures to complete an operation. Most users preferred utilizing controllers for interactions rather than hand tracking. In particular, for novice users, pushing a button on a controller is considered more convenient and accessible than using hand gestures. On the other hand, according to the data, there is a slight increase in the use of hand interaction in MR environments. According to statements of the users, during their MR experiences, they wanted to manipulate the digital objects as if they are real to create more consistent interaction in parallel to their blended vision.

The incorporation of visual stimuli into virtual environments has been demonstrated to effectively stimulate human emotions and behaviors, thereby increasing the overall efficacy of these environments. The visual integrity of these stimuli enhances the realism and immersion of the environment and can support a range of tasks and activities within it. This may involve utilizing a variety of colors, intensities, and directions of light to generate diverse effects and accommodate the needs of the user, which can influence emotions, behaviors, decision-making, and health [87]. Providing a change in the lighting temperature we investigated the lighting preferences of participants in curator/designer and visitor modes/roles in VR and PC environments.

Overall, users reported that they were more able to focus on details and pay attention to the finer aspects of the exhibits under cold and neutral lighting conditions. On the other hand, warmer temperatures seemed to contribute to a sense of comfort and relaxation during observation, which may have allowed users to feel more at ease and less stressed while viewing the exhibits. This may have resulted in a more enjoyable and immersive experience for the users. It is worth noting that these findings may change according to specific exhibits and displays being viewed, as well as the design and layout of the interior space.

6.2. Procedural Generation of Environmental Content

Heterotopias, as described by Michel Foucault, are physical spaces that operate outside of mainstream cultural norms and challenge the power dynamics that exist within society. These spaces, create a different "order of discourse" by disrupting the dominant syntax of other norms. In architecture, the balance of control and power between the designer, technology, user, and surrounding environment is a central consideration. The increasing incorporation of technology into the built environment has the potential to alter this balance, leading to debates within the field on the appropriate level of autonomy for these systems and the implications for the user experience and the distribution of power. The relationship between architectural design and the tools used to create it is inherently intertwined. As technology has progressed, design practices within the field have undergone a shift from physical to digital processes. From drafting and representation to construction and, most significantly, the design itself, the incorporation of modern technologies has had a profound impact on the production and final output of architectural projects. It is important to note that the resistance to these technological advances often originates from the tools themselves rather than the user, indicating a larger trend in the integration of technology into the field of architecture.

Given that procedural generation is essentially predetermined, users may add uniqueness and variation to their work by incorporating human design components into the usage of automated generation methods. By providing dynamic power relations and various autonomy levels for automated generation algorithms, we aimed to investigate the impact of autonomy and user preferences on the result, particularly the extent to which the method produced the desired outcome while taking into account the balance between usability and understandability in the design process. It is crucial to understand how users perceive the various outcomes. To compare the performance of different algorithms, participants were first asked to evaluate versions of the algorithms that were based on data and versions that were randomly generated, and then they proceeded to versions based on user preferences.

According to the findings, the growth algorithm offered users the highest comprehensibility while BSP has the lowest score. The growth algorithm only permitted users to select the starting point for room expansion, with the algorithm determining the shape and configuration of the resulting rooms. While users found the growth algorithm to be less customizable in comparison to the other options, they appreciated the ability to view and select the initial area of operation, which enhanced their understanding of the algorithm's functionality. The room generation algorithm allows the user to control both the placement and size of the final product whereas, with the BSP, users could choose the dimensions of the rooms, but the placement was controlled by the algorithm. Overall, the BSP algorithm provides a higher level of perceived control than the growth algorithm, but a lower level than the room generation algorithm. The BSP algorithm offered a higher number of options than the room generation algorithm, but users perceived it as providing less control and ease of use. In the data-based version of the algorithms, the BSP algorithm displayed lower comprehensibility, but it generated the most successful design output according to participant evaluations. These outcomes were also considered superior in terms of quality and diversity. However, the BSP algorithm had lower comprehension among participants in comparison to the other options. When participants were able to provide preferences, comprehension increased, but this also resulted in a decrease in the design output produced by the algorithm. This suggests that the data-based version of the algorithm may be more effective at meeting users' design needs compared to the user-based version. On the other hand, the room generation algorithm offered the highest levels of perceived control, design outcome, and ease of use in user-based versions.

The scale of the environment is a crucial factor that can significantly influence how users interact with it. This is because the level of detail, the organization of content, and how to select items to manipulate are all affected by spatial perception. In virtual environments, users' spatial experiences enable them to actively process and interpret their surroundings, which can lead to different design approaches based on the embodiment level, point of view, and scale of the interface. As a result, the scale of an environment has a significant impact on user engagement. It is important for a system to carefully consider the scale of an experience to create an effective and user-friendly experience. A comparative analysis of the different algorithms reveals that the BSP algorithm can generate large-scale designs, while the room generation algorithm is limited to the creation of a single space and the growth algorithm can populate within predetermined boundaries. User preferences for these algorithms were influenced by the specific platform on which they were used. In the PC version, where a top-down view was available, the BSP algorithm was preferred to gain control over design. The room generation algorithm was more frequently chosen in the MR version, where users could alter their virtual surroundings. The growth algorithm was considered the most appropriate for the VR version, as it allowed for the creation of multiple rooms while maintaining user navigational ability with less complexity than BSP.

6.3. Usability, Technology Acceptance and Presence

One of the primary goals of this study was to create a user-friendly framework for immersive technology based on the concept of heterotopias, suitable for a diverse range of users including both beginners and experts. The ability to effectively navigate and engage with the system has the potential to significantly alter an individual's level of control and agency within it. Therefore, a high level of usability and acceptance is essential to prove the existence and level of users' autonomy. Designing a framework that could be easily used and accessed by a diverse audience, including those with varying levels of familiarity and expertise, was one of the main goals of this research. To assess the effectiveness of the different versions of the framework in this regard, the Technology Acceptance Model and the System Usability Scale were employed. The SUS includes a set of questions that evaluate the complexity, consistency, and ease of use of the system, and the results demonstrated that all three versions of the framework scored within a similar range on these metrics. This suggests that, from a usability perspective, we were successful in creating a standard level of usability across the different technologies. However, there were some diverse reactions from the participants regarding the usability of the different versions, with many stating that the virtual reality version was the most engaging, despite its slightly lower usability scores compared to the other versions.

[P.17] "I can use the VR version for hours when I want to get away from reality."

[P.04] "MR version was pretty interesting, the PC version was easier to use, but VR was more fun."

Throughout the development process, we tried to maintain a balance between the framework's feature-richness and its overall simplicity. SUS and TAM assessments indicate that we were able to achieve this balance to some extent. However, linear regression analysis revealed that the performance of the framework was positively correlated with the participant's experience with similar tools. Specifically, while most participants with limited prior experience were able to quickly adapt to the features, a minority of them reported difficulty due to the number of features, which resulted in decreased usability and increased cognitive load, ultimately resulting in decreased levels of presence. Overall, these findings suggest that when designing user-centered systems, it is essential to consider the trade-off between the number of features and simplicity.

[P.25] "I think the number of features should be less. I felt there are so many features to use which put me under stress."

According to frequency analysis, while MR and VR versions of the framework were described as "experimental," "useful," "quick," "functional," and "interesting" by users, it was also described as "difficult," "hard," and "complex." On the other hand, the PC version was found "easy" and interpreted as a more game-like environment. The high volume of information within heterotopias provided an "experimental" and "creative" space for users but also manifested through interfaces surrounding the users which may cause overload for novice users. Some participants noted that the abundance of features hinders usability and increases cognitive load, disrupting the sense of immersion.

An analysis of TAM's subsections was conducted to gain a more comprehensive understanding of the results. The section on the perceived usefulness of the system included questions related to how effective, productive, and efficient they are with the system provided. While the PC version received the highest scores in this category, the results for the other versions of the system were similar to each other in terms of

PU. The perceived ease of use section of the survey evaluated the clarity and simplicity of the interaction between the system and the user, as well as the level of skill required to use the system. In this research, the perceived ease of use of mixed reality and virtual reality technologies was discovered to be an essential element in predicting a user's tendency to accept and embrace the technology. In terms of PEU, the findings indicated that VR scored lower than MR. Also, experienced users tended to give higher scores to PEU and lower scores to PU compared to novice users. The results also showed that MR was perceived as being easier to understand and requiring less effort to use than VR. Through a combination of questionnaire results and semi-structured interviews, it was revealed that the lower ratings for VR may be related to its immersive character, which might alienate the user from the external world. This implies that the design and nature of VR technology may influence its PEU and, ultimately, user acceptability and adoption.

According to the feedback from users in this study, the MR version was perceived to be safer than the VR version, but the VR version was perceived as more enjoyable to use. The headset used in the study has a feature that reveals the real-world environment when it detects an object nearby. However, novice users who were not accustomed to being fully immersed in an artificial world may have had less trust in the technology and preferred to use the teleportation option for navigation, which reduced their interaction with the virtual environment. This may have contributed to the lower scores for VR in terms of ease of use compared to MR.

[P.03] "Since I was able to see the physical environment, I felt safer in MR than VR."

[P.19] "I became disoriented in the VR, and at one point I felt constrained by the headset and wanted to remove it. The MR version was not as impressive as the VR version, but I would prefer to use the MR version."

The adoption and utilization of technology are significantly influenced by trust, which increases the possibility of utilization of certain technologies [142]. Within the framework, all versions are generated from the same system, which allows them to maintain the same degree of predictability in terms of performance and utility. However, utility and other elements interact with one another. Therefore, lower technical dependability may cause lower perceived usability in VR.

The results of the TAM and SUS questionnaires indicated that the personal PC version was perceived as more effective and easier to use, which was consistent with our expectations given the participants' previous experiences. However, we anticipated that the virtual reality version would exhibit the highest levels of presence. Further analysis of the responses to questions related to cognitive load and user concentration suggests that the varying degrees of familiarity with the interaction modalities may cause higher scores for the PC version and lower scores for the VR and MR versions. While keyboard and mouse interaction and traditional screen views are commonly utilized and familiar to most users, it appears that the hand or controller interaction required in VR and MR may have taken more time for users to become accustomed to, potentially hindering their ability to fully engage with the immersive environment and resulting in lower scores.

To acquire a more complete understanding of the results of this study, we conducted a more in-depth analysis of the responses to specific questions within the questionnaire. The questionnaire included a section on realism, which asked participants to evaluate the naturalness of interaction and movement, the visual features of the system, how well it matched real-world experiences, and how engaging it was. When the results were analyzed separately, it was found that while the virtual reality and mixed reality versions of the system received higher scores in terms of visual aspects, consistency with real-world experiences, and engagement, the personal computer version received higher scores in terms of naturalness of interaction and movement. This unexpected result led us to investigate further to understand the underlying problem further. When the system was evaluated by participants and compared to real-world experiences, it was revealed that VR and MR engagements were more relevant. However, the phrase "natural" may have prompted participants to rethink their instinctive behaviors, leading them to view keyboard and mouse interaction as more "natural" for casual, mid-core, and hard-core gamers, which may have contributed to the observed score disparity.

During the self-assessment section of the questionnaire, users were asked to evaluate themselves in terms of proficiency to use the system, as well as their ability to control events, survey the environment within the system, and assess the responsiveness of the environment according to their actions. While all versions of the system provided similar levels of control, the PC version offered a range of camera options that were found to allow for more effective surveying of the environment, particularly when using the top-down camera. During interaction with the mixed reality version, many users initially preferred to use hand gestures to control the system. However, they often encountered difficulties in accurately gauging the position of their hands relative to the detection area of the headset, which may have affected their ability to effectively use hand gestures for control. This may have contributed to the lower scores for the MR version in the self-assessment section of the questionnaire. To improve the usability of the MR version, guidance to users on the proper positioning of their hands is necessary.

Several factors were taken into consideration during the examination, such as the distance between the user and the system, the availability of viewpoints for the user, and the user's ability to focus on the task at hand. Participants' feedback indicated that the coexistence of physical and virtual content causes distractions, which may have contributed to the lower scores for the mixed-reality version in this regard. When it came to the number of viewpoints available, the PC version outperformed the other versions, offering a greater number of camera angles that allowed users to survey their environment more easily, resulting in higher scores. The quality of the interface was assessed through questions regarding the delay, the visual display quality, and the performance of the control devices. Observations revealed that the number of objects placed by the users varied depending on the environment. The PC and VR versions did not initially have visible boundaries in the perceived environment, while the MR version had visible boundaries dictated by the physical space in which the users were located. As a result, users tended to place more objects without deleting them in the PC and VR versions, while most users in the MR version preferred to stay within the physical boundaries. This may have been due to the user's unfamiliarity with the system. The MR version was able to achieve the highest quality interface score when using the same device, possibly due to its ability to integrate virtual objects more smoothly into the physical environment. It is worth mentioning that the PC version had a significant advantage in terms of computational and graphics capabilities; however, the headset used for the VR and MR versions had limited capacity, leading to instability in the frame rate and lower scores for the visual display in the VR version when users exceeded the limits of the headset.

The findings indicate that various technologies can influence cognitive load and user attention differently, and it is crucial to take these factors into account when selecting a technology for a specific task. Overall, the total scores suggest that a multi-layered approach to creating heterotopias with the specified features achieved high scores in terms of presence, usability, and acceptance among users with varying experiences.

CHAPTER 7

CONCLUSION

7.1. Conclusion

The discursive space is a realm of intellectual exploration, a place where knowledge and understanding can be examined and disseminated. It encompasses the acquisition of insight and enlightenment through the investigation and examination of specialized knowledge about the world. In today's digital age, multimedia has become the dominant mode of communication and the language of discursive practices. Heterotopias are extraordinary, multidimensional contexts that facilitate the dissemination of information and connect other systems through "surfaces of emergence." These contexts stand out for their ability to contain and connect a wide range of perspectives.

This research outlines a methodology and presents a framework for creating multilayered digital spaces, based on the concept of heterotopias, that facilitate the exchange of knowledge and information across virtual and mixed reality environments and personal computers. The framework addresses the disappearing layers in archival practices in the digital age and presents "liquid architectures" that can adapt according to users' needs. The use of virtual museums as "operating tables" for discursive methodologies was proposed, offering dynamic rather than static settings for the exploration and dissemination of information.

The effectiveness and versatility of the framework were demonstrated through a study involving 30 participants and found easy to use and adaptable to various settings. The results of qualitative and quantitative analyses highlighted the transformative power of heterotopias, and the various algorithms implemented—including Binary Space Partitioning, Cellular Automata, Growth Algorithm, and Procedural Room Generation—offered users different levels of control over the design process. Findings suggest that the interplay between place production, transformation, and archival practices plays a crucial role in facilitating "self-formation" activities. By integrating the layers of heterotopias with digital technologies, users were provided to experience "aesthetic becoming" at various levels of reality and become "focal points of resistance" through the fusion of meta-design and end-user development approaches.

Various factors that influence user experiences and preferences were examined to inform future work in the field of human-computer interaction. Three different versions of the design were evaluated through the use of questionnaires and interviews.

The unique characteristics and strengths of each version were highlighted in the findings, and a comparative analysis was conducted to demonstrate how different levels of reality can enhance users' abilities in the curation of digital habitats. The hybridity of physical and digital spaces, interactions, the perceived meaning of the space, and the elements within it were also investigated and found to be subject to different reinterpretations by users on virtual reality, mixed reality, and personal computer platforms.

7.2. Limitations and Future Work

The HMD we used in this study may have affected the results of the study. We optimized the digital content provided by the framework to avoid differences caused by the computational capacities of the HMD and PC. However, personal content imported by the users may cause technical problems due to the complexity or size of the files, such as lagging and lower frames per second rates. Also, it is only capable of providing the physical world in grayscale which is also a parameter to be considered. During every stage of the design process, we keep it in mind to refrain from any methods that may prove difficult for first-time users. This framework focused on important characteristics to build a system for a variety of settings. Therefore, we did not provide particular technological prerequisites for a certain practice. On the basis of the structure of the framework, modules may be added to serve various professions.

According to the literature analysis, most architects and designers prefer to work with several displays and different sorts of representations. With the additional modules including sketch-based interactions, this framework is able to resolve colocation issues in design processes and deliver more thorough production. We employed four factors based on museology that might be reinterpreted by users to rearrange the information. However, characteristics for different sorting strategies can be produced for more complicated structures. Not delivering audio assets in line with physical distance is one of the variables that might impair the environment's authenticity. Sound localization may be used to enhance the realism of the environment and make navigation through these areas more natural and intuitive. According to the views of participants, the number of available options might be intimidating for some inexperienced users. Therefore, functionalities may be offered separately at various expertise levels. In the current investigation, comparison testing was performed on several different aspects that may call for further theoretical considerations. One of the topics that have not yet received sufficient attention is the interaction with text in immersive settings. Additionally, the use of voice commands may open up new avenues of exploration. In this study, individual experiences were investigated independently for each technology to compare and understand preferences and effects. Future research may incorporate both asymmetric and symmetric collaborative techniques. Adding a social layer within a more transformational mechanism between PC and immersive technologies might enrich the depth of heterotopias as well as the framework's usability.

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APPENDICES

APPENDIX A

A.1 SYSTEM USABILITY SCALE [137]

Please place an "X" in the appropriate box to rate the following items using a scale of 1–5: 1=Strongly Disagree 5=Strongly Agree.

	1	2	3	4	5
I think that I would like to use this application frequently.					
I found this application unnecessarily complex.					
I thought this application was easy to use.					
I think that I would need assistance to be able to use this application.					
I found the various functions in this application were well integrated.					
I thought there was too much inconsistency in this application.					
I would imagine that most people would learn to use this application very quickly.					
I found this application very cumbersome/awkward to use.					
I felt very confident using this application.					
I needed to learn a lot of things before I could get going with this application.					

A.2. ADAPTED TECHNOLOGY ACCEPTANCE MODEL QUESTIONNAIRE [140]

Please place an "X" in the appropriate box to rate the following items using a scale of 1–7: 1=Extremely Unlikely 7=Extremely Likely.

	1	2	3	4	5	6	7
Perceived Usefulness							
Using this application would enable me to perform more quickly than other products in its class.							
Using this application would improve my design performance.							
Using this application would increase my productivity.							
Using this application would increase my effectiveness.							
Using this application would make it easier to design.							
I would find this application useful.							
Perceived Ease of Use							
Learning to use this application is easy for me.							
My interaction with this application is clear and understandable.							
It would be easy for me to become skillful at using this application.							
I would find this application easy to use.							

A.3. PRESENCE QUESTIONNAIRE [136]

(PART I)

Please place an "X" in the appropriate box to rate the following items using a scale of 1–7: 1=None 7=A lot.

	1	2	3	4	5	6	7
Realism							
1. How natural did your interactions with the environment seem?							
2. How much did the visual aspects of the environment involve you?							
3. How natural was the mechanism which controlled movement through the environment?							
4. How compelling was your sense of objects moving through space?							
5. How much did your experiences in the virtual environment seem consistent with your real-world experiences?							
6. How compelling was your sense of moving around inside the virtual environment?							
7. How involved were you in the virtual environment experience?							
Self-Evaluation of Performance							
8. How quickly did you adjust to the virtual environment experience?							
9. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?							
Possibility to Act							
10. How much were you able to control events?							
11. How responsive was the environment to actions that you initiated (or performed)?							
12. Were you able to anticipate what would happen next in response to the actions that you performed?							
13. How completely were you able to actively survey or search the environment using vision?							

A.4. PRESENCE QUESTIONNAIRE [136]

(PART II)

	1	2	3	4	5	6	7
Possibility to Examine							
14. How closely were you able to examine objects?							
15. How well could you examine objects from multiple viewpoints?							
16. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?							
Quality of Interface							
17. How much delay did you experience between your actions and expected outcomes?							
18. How much did the visual display quality interfere with or distract you from performing assigned tasks or required activities?							
19. How much did the control devices interfere with the performance of assigned tasks or with other activities?							

A.5. TOOL COMPETENCE

Please place an "X" in the appropriate box to rate the following items using a scale of 1–7: 1=None 7=A lot.

	1	2	3	4	5	6	7
What was your previous experience with VR simulations?							
What was your previous experience with Mixed Reality?							

A.6. LIGHTING PREFERENCES

Please place an "X" in the appropriate box.

	Cold	Neutral	Warm
Which lighting temperature did you prefer as a curator in VR environments?			
Which lighting temperature did you prefer as a visitor in the VR environment?			
Which lighting temperature did you prefer as a curator in the PC environment?			
Which lighting temperature did you prefer as a visitor in the PC environment?			

A.7. INTERACTION PREFERENCES

Please place an "X" in the appropriate box.

	Hand Interaction	Controllers
Which one do you prefer in a VR environment?		
Which one do you prefer in the MR environment?		

A.8. INTERACTION PREFERENCES WITH ASSET

Please place an "X" in the appropriate box.

	PC	VR	MR	PC Canvas	VR Canvas	MR Canvas
Which medium was more suitable for the interaction with painting assets?						
Which medium was more suitable for the interaction with text assets?						
Which medium was more suitable for the interaction with video assets?						
Which medium was more suitable for the interaction with sculpture assets?						
Which medium was more suitable for the interaction with audio assets?						

A.9. PROCEDURAL CONTENT GENERATION QUESTIONS
(Based on User Preferences)

Please place an “X” in the appropriate box.

	Growth Algorithm					Room Generation					BSP and Cellular Automata				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
How much were you able to control the design outcome?															
How compelling was the design outcome according to your place’s requirements?															
How easy was using the algorithm?															
How much were you able to anticipate the process of the algorithm in response to your preferences?															

A.10. PROCEDURAL CONTENT GENERATION QUESTIONS
(Based on Data)

Please place an “X” in the appropriate box.

	Growth Algorithm					Room Generation					BSP and Cellular Automata				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
How compelling was the design outcome according to your place’s needs?															
How much were you able to anticipate the process of the algorithm?															

APPENDIX B

INTERVIEW QUESTIONS

Please answer the following questions.

1. What is your general opinion about the framework?
2. What are the main potential employment areas of the framework?
3. Which version do you think is more effective and appropriate to construct personal virtual environments and why?
4. What are the main limitations of the framework?
5. Which additional features will be useful to improve the experiences?
6. What are your suggestions to improve the interaction and flow?
7. What are your suggestions to improve the visual perception and interface design?
8. How did the changes in lighting and skybox settings affect your design perception?
9. How much benefit did you get from automated generation algorithms?
10. How much benefit did you get from the analysis of the data?
11. How easy was it to perceive and understand the asset analysis results in the virtual environment?

APPENDIX C

ETHICAL APPROVAL

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14 NİSAN 2022

Konu : Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi : İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Elif SÜRER

Danışmanlığını yürüttüğünüz Elif Hilal KORKUT'un "Otomatikleştirilmiş Sanal ve Sürükleyici Müze Deneyimlerinin Yaratımı ve Kullanıcı Deneyiminin Değerlendirilmesi " başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **0244-ODTUİAEK-2022** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof.Dr. Mine MISIRLISOY
İAEK Başkan

APPENDIX D

SUPPLEMENTARY FIGURES

Figure D1: Photos of the participants while they were experiencing framework with Oculus Quest 2 and Oculus Quest 2 Controllers.

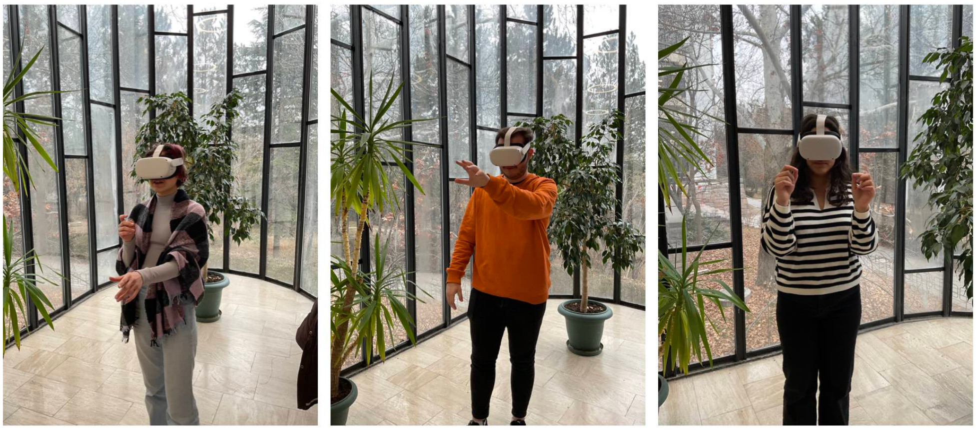

Figure D2: Photos of the participants while they were experiencing framework with Oculus Quest 2 with hand interaction.

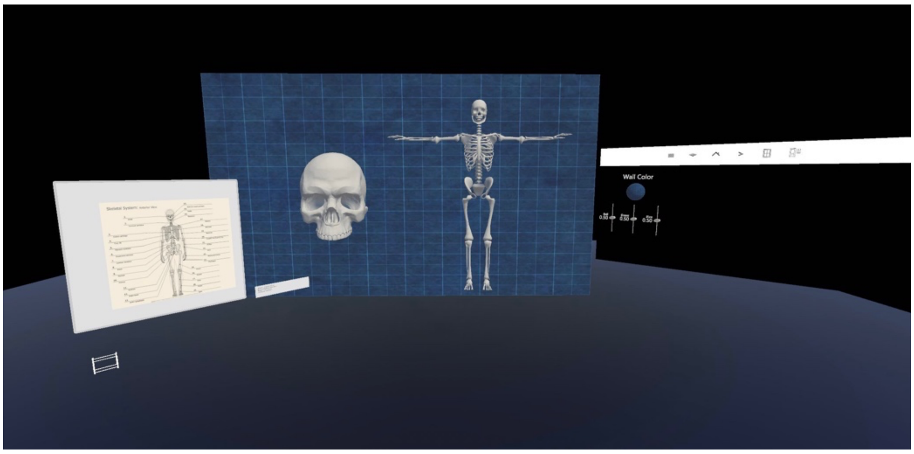

Figure D3: Composition in VR Environment.

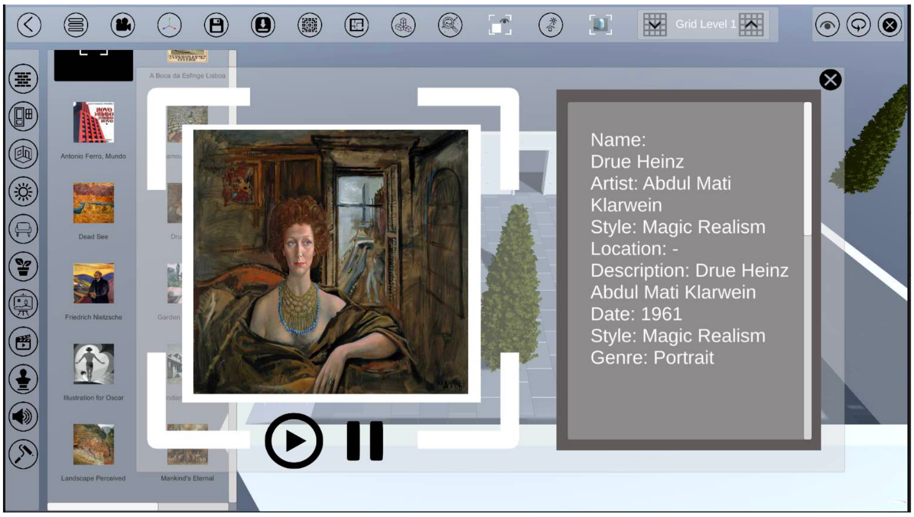

Figure D4: ArtCanvas View.

Figure D5: Keyboard interaction in VR.

Figure D6: Artifact Analysis Panel.

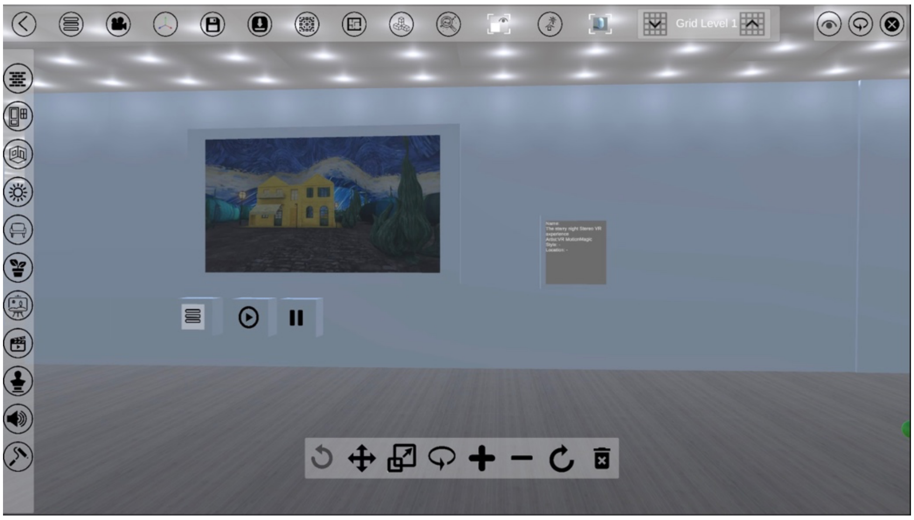

Figure D7: Artifact Holder for video assets.

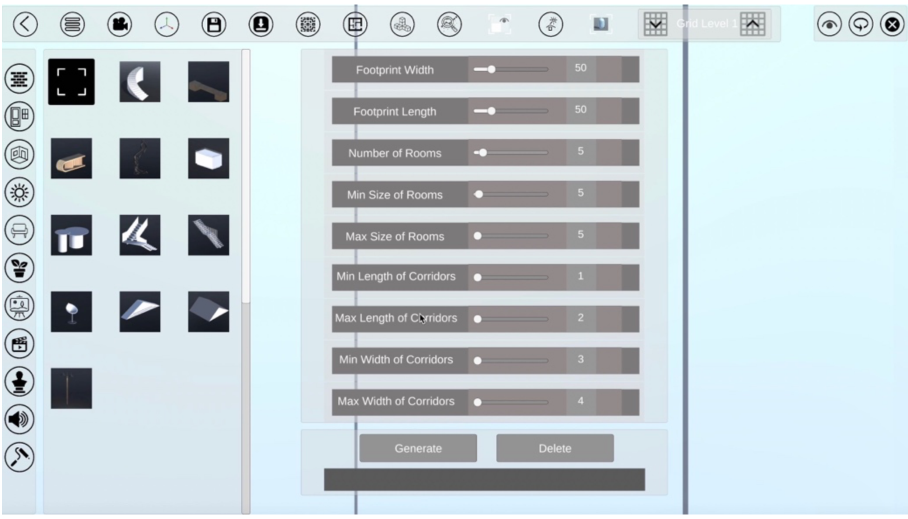

Figure D8: Interface example for algorithms.

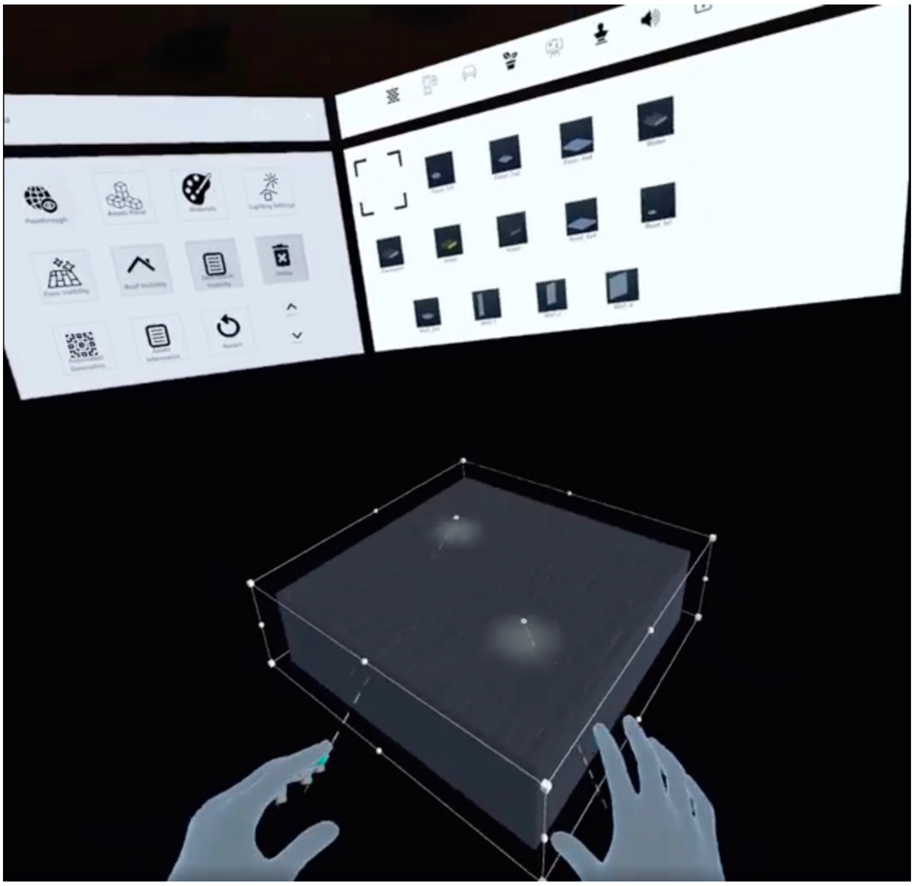
Figure D9: Manipulation with two hands.