석 사 학 위 논 문
Master's Thesis

물리적 책상 위 3D 가상 제어를 활용한 몰입형 저작 인터페이스

Immersive Authoring Interface with 3D Virtual Controls on Physical Desk

2023

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한 국 과 학 기 술 원

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Immersive Authoring Interface with 3D Virtual Controls on Physical Desk

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A dissertation submitted to the faculty of
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Approved by

Woohun Lee
Professor of Industrial Design

The study was conducted in accordance with Code of Research Ethics[1].

[1] Declaration of Ethical Conduct in Research: I, as a graduate student of Korea Advanced Institute of Science and Technology, hereby declare that I have not committed any act that may damage the credibility of my research. This includes, but is not limited to, falsification, thesis written by someone else, distortion of research findings, and plagiarism. I confirm that my thesis contains honest conclusions based on my own careful research under the guidance of my advisor.

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초 록

최근 증강 현실과 가상 현실 기기의 보급으로 인해, 몰입형 저작 도구에 대한 수요가 증가하고 있다. 그러나 창의적인 작업에서 빼놓을 수 없는 복잡한 제어 패널 화면은 자연스러운 손 상호작용에 대한 어려움을 유발하여 이 분야의 탐구가 제한되고 있다. 본 논문에서는 2D 제어 패널을 가상의 3D 객체로 표현하는 몰입형 저작 인터페이스 Desk Console을 제안한다. 이 인터페이스는 일상적인 책상을 통해 촉감 피드백을 제공하며, 입력 유형에 따라 기존 사용자 인터페이스를 3D로 분류하여 유연성을 제공한다. 인터페이스의 성능과 창의성 지원에 대한 영향을 조사한 결과, 사용자들은 Desk Console로 기능을 효율적으로 활용할 수 있었고, 수동적인 햅틱 피드백으로 낮아진 작업 부하, 적극적인 디자인의 탐색 및 표현을 통한 몰입감 있는 작업 경험을 했음이 드러났다. 이 연구는 자연스러운 직관적 상호작용을 통해 창의적인 작업을 지원하는 솔루션을 제공함으로써 몰입형 저작 분야에 기여하며, 증강 및 가상 현실 환경에서의 미래 업무를 향상시키는데 도움이 될 수 있다.

핵 심 낱 말 가상 현실, 몰입형 저작, 창의력 지원 도구

Abstract

As augmented reality and virtual reality devices become prevalent, there is a growing need for immersive authoring tools. However, the complex control panel screens that creative work inevitably involves challenges for natural bare-handed interaction, resulting in limited exploration in this area. This thesis presents Desk Console, an immersive authoring interface that represents the 2D control panel as a virtual 3D object on a desk. By utilizing everyday desks for tactile feedback and categorizing existing user interfaces into 3D representations based on input types, this interface offers flexibility. The interface's performance and its impact on the authoring experience were investigated, revealing that Desk Console enables efficient utilization of functions, reduces workload through passive haptic feedback, and facilitates exploration and expression of designs, leading to a pleasant and immersive work experience. This research contributes to the field of immersive authoring by providing a solution that supports creative work through natural and intuitive interactions, thereby enhancing the future of work in augmented and virtual reality environments.

Keywords Virtual reality, immersive authoring, creativity support tool

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1.
INTRODUCTION

Chapter 1. Introduction

1.1 Background

In recent years, Augmented Reality and Virtual Reality (AR/VR) technologies, facilitated by Head-Mounted Display (HMD) devices like Apple Vision Pro[1], Meta Oculus Quest 2 [2] or Microsoft HoloLens[3], have gained popularity and are shaping the future of our envisioned workspace. The introduction of Oculus Infinite Office [4] by Meta showcases the potential for working in various locations using HMD devices (Figure 1.1). However, the interaction with virtual screens using bare hands remains somewhat uncomfortable for complex tasks, limiting the feasibility of work without additional equipment. This issue becomes more pronounced with control panel interfaces for creative work that have complex and dense input elements, as shown in Figure 1.2.

Figure 1.1: Meta Oculus Infinite Office Enabling Work Anywhere

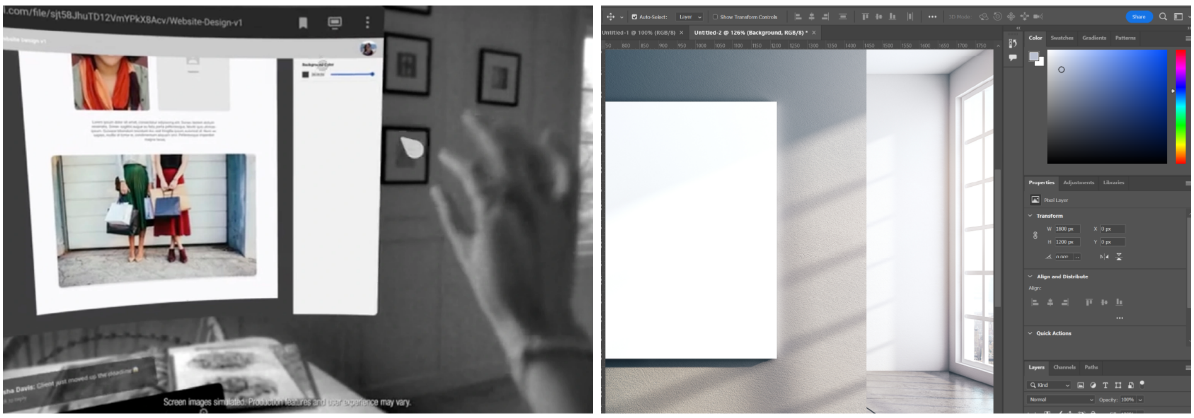


Figure 1.2: Challenges in Virtual Work:
(Left) Bare-hand Interaction with Virtual Screen, (Right) Complex Creative Tool Interface

[1] https://www.apple.com/apple-vision-pro/
[2] https://www.meta.com/quest/products/quest-2/
[3] https://www.microsoft.com/hololens
[4] https://youtu.be/5_bVkbG1ZCo

Consequently, previous attempts have been made to improve the traditional interface to support Immersive Authoring [26] that enables users to intuitively create content within the AR/VR environment [35, 47]. As augmented reality and virtual reality inherently involve spatial interfaces and interactions, the content is predominantly designed in three dimensions (3D) to leverage spatiality. This poses challenges when designing on traditional flat 2D screens, as spatial information is lacking, leading users to repeatedly wear and remove the HMD to check the designed content—a cumbersome and inefficient process. Thus, there is a growing demand for immersive authoring solutions. However, most existing immersive authoring tools require additional equipment, such as controllers or mouse devices, to ensure stable manipulation. This approach does not fully exploit the potential of augmented and virtual reality for natural and enriched interactions.

Therefore, this thesis aims to embrace the future of work by enabling intuitive and natural interactions with complex control panels typically encountered in creative work through bare-handed manipulation, eliminating additional equipment. Our proposed interface facilitates rich and natural interactions while ensuring stable manipulation of elements from the existing 2D Graphic User Interface (2D GUI) within virtual reality. The study aims to verify the effectiveness of this interface in supporting creative work.

1.2 Research Objectives

This thesis aims to design an immersive authoring interface that facilitates virtual 3D controls on a desk, corresponding to the existing 2D Graphical User Interface (2D GUI) -based control panel UI. The primary objective is to enhance the performance of the interface and investigate its impact on users' creative work experience. The study focuses on users' creative tasks conducted within personal workspaces in virtual environments.

In interface design, the research categorizes and represents the existing applications' UI in interactable 3D objects. Additionally, the desk surface, a common object in a workspace, is integrated to provide passive haptic feedback. The evaluation not only assesses the performance of the interface but also examines how it supports users' creative work. To achieve these objectives, the study aims to address the following questions:

- **RQ1a.** What are current user experiences of creative work with virtual screens?
- **RQ1b.** How can an immersive authoring interface be designed to enable intuitive and natural interaction, while ensuring the stability of bare-handed operation with a virtual control panel?
- **RQ2.** How does the designed interface impact users' authoring experience, and to what extent does it enhance various aspects of creativity support?

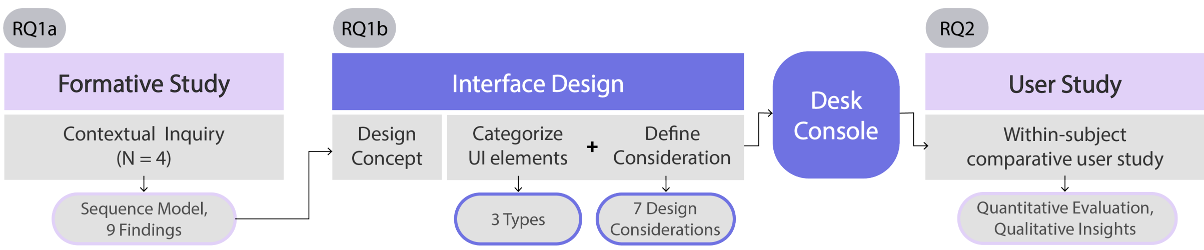


Figure 1.3: Thesis Objectives Overview

1.3 Thesis Composition

The structure of this thesis is as follows:

- **Chapter 1** provides an introduction to the study, including its background and objectives.
- **Chapter 2** encompasses the previous cases of immersive authoring in the AR/VR field. It discusses the need for improved 2D interaction in virtual environments and explores the impact of 3D representation on supporting creativity in related works.
- **Chapter 3** presents the findings from a contextual inquiry that investigated the specific user experience during creative tasks in a virtual environment. It defines the characteristics of creative tasks, virtual reality work, and identifies associated pain points.
- **Chapter 4** details the design process and implementation of the Immersive Authoring Interface with a 3D Represented Control Panel on Desk, Desk Console. It includes the steps involved in designing the interaction.
- **Chapter 5** describes a user study conducted to evaluate the Desk Console's impact on user experience. It examines performance, workload, creativity support, and user behavior, compared with existing interface.
- **Chapter 6** explores the potential extensions of the Desk Console to support the real-world work of users, drawing from the evaluation results.
- **Chapter 7** provides a summary and highlights the research process, major contributions, and outcomes of the Desk Console.

2.
RELATED WORKS

Chapter 2. Related Works

This section introduces Immersive Authoring in Augmented Reality (AR) and Virtual Reality (VR), and more natural interactions in authoring tools are examined. Following this, we discuss the 2D Graphical User Interface (GUI) interaction and creative support aspects of 3D authoring tools. It explores the ongoing need for 2D GUI interaction in 3D authoring tools and examines its implementation in virtual environments. Finally, we investigate how interfaces incorporating 3D representation facilitate creativity in the authoring process.

2.1 Immersive Authoring Interface in AR/VR

Immersive authoring enables users to intuitively view and create 3D content through a "What You See Is What You Get (WYSIWYG)" environment [26]. This provides immediate feedback on 3D content along with rich spatial information, freeing users from the tedious and repetitive loop of working on a 2D desktop and checking with an HMD device. Previous works have designed immersive authoring tools that overcome the limitations of traditional interfaces in various creative areas, including 3D sketching and modeling [6, 37, 20, 2], scene development [45, 47, 41], and 360 video production [35, 14]. However, most of these tools require a controller or mouse for stable manipulation, which reduces portability and immersion due to less natural interaction [31, 32].

Figure 2.1: Immersive Authoring Interface in Virtual Reality:
(a) Google Tiltbrush [20], (b) Gravity Sketch [39], (c) FlowMatic (UIST'20) [47]

Cases using bare-hand interaction [43] to free users' hands can easily be found in AR authoring tools. These tools, exemplified by Teachable Reality [34] and UbiEdge [22], as well as the case of SceneCtrl [46], actively incorporate objects, surfaces, edges, and environmental elements into the authoring process. The concept of leveraging commonplace objects and environments as user interfaces has garnered significant attention within the HCI domain. Notably, this approach provides users with passive haptic feedback, as demonstrated in Substitutional Reality [38] and Annexing Reality [23], offering a means to heighten immersion and presence in AR and VR without additional equipment. Moreover, prior investigations [27] have revealed that passive haptic interfaces can augment task performance. Hence, our work involves designing an immersive authoring interface utilizing the everyday object desk as a user interface to capture both stability and natural bare-hand interactions in manipulation.

Figure 2.2: Interfaces leveraging surrounding objects and environments:
(a) Substitutional Reality: VR overlaid on physical objects [38] (b) Annexing Reality: Everyday objects as tangible proxies [23] (c) Ubi Edge: Interface using edges of everyday objects [22]

2.2 Screen Interaction in Virtual Environment

Many authoring tools have embraced 3D manipulation instead of 2D Graphic User Interface (GUI) to facilitate intuitive interactions and immersive workflows (Figure 2.1). However, the creative process involves both creation and the exploration of reference materials, necessitating interaction with 2D screens. This is because screens, even in a 3D environment, remain efficient in conveying information[15]. Failure to address these considerations would result in users repeatedly transitioning between the real and virtual worlds, constantly donning and removing HMD devices for individual tasks. Therefore, it is crucial for 3D authoring tools to incorporate some level of 2D screen interaction. Current VR applications that primarily rely on 2D screen interaction (e.g. Oculus Link [1], Immersed [2], vSpatial[3], etc.) offer users the ability to immerse themselves in familiar interfaces while exploring information and verifying content. These applications directly transfer the desktop screen into VR, facilitating user adaptation. However, interaction based on ray casting lacks spatial experience and may not be ideal due to its sensitivity to distance and target object size.

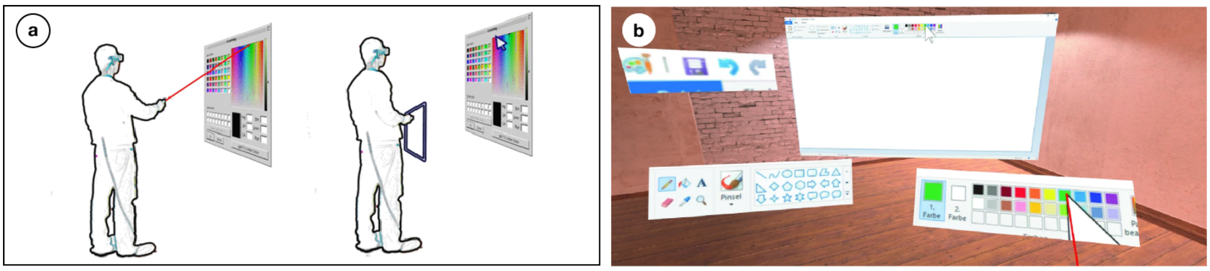


Figure 2.3: Interaction approaches for 2D GUI within reachable distance:
(a) Classic raycasting and Virtual Pads, the motor space is decoupled from the visual space [4]
(b) Extracted panels from the original window to a reachable distance [25]

Previous research has explored comfortable interaction with 2D GUI within virtual environments. Bending ray casting, for instance, allows users to easily grab nearby elements, reducing pointing fatigue [3, 42]. Nonetheless, interacting with distant 2D GUI requires users to operate indirectly or deviate from their comfortable posture, resulting in awkwardness. To address this, Virtual Pads [4] placed virtual pads within users' reachable distance for comfort zone interaction, while Adrian.H. et al. [25] replicated frequently used UI elements in users' immediate surroundings. In line with these findings, our interface

[1] https://www.meta.com/help/quest/articles/headsets-and-accessories/oculus-link/
[2] https://immersed.com/
[3] https://www.vspatial.com/

enables users to manipulate 2D GUI elements within reachable distances, maintaining a comfortable posture. Additionally, by considering 2D GUI interaction in a 3D authoring environment, our interface encompasses the entire design process, including information exploration and content creation.

2.3 3D Representation for Creativity Support

Virtual and augmented reality hold the potential to provide rich spatial experiences by representing abstract concepts and 2D information in a 3D format. By leveraging this potential effectively, it is possible to design immersive and intuitive authoring tools that allow for natural and realistic workflows in virtual environments [11]. Lindeman et al. [28] demonstrate the effectiveness of 3D interface widgets in enhancing specific 2D interactions in virtual environments. Similarly, Weiss et al. [44], comparing 2D and 3D interfaces, show that 3D interfaces excel in fun, immersion, naturalness, and intuitive manipulation. Such enjoyable and intuitive interactions are crucial in authoring tools as they support users' creativity.

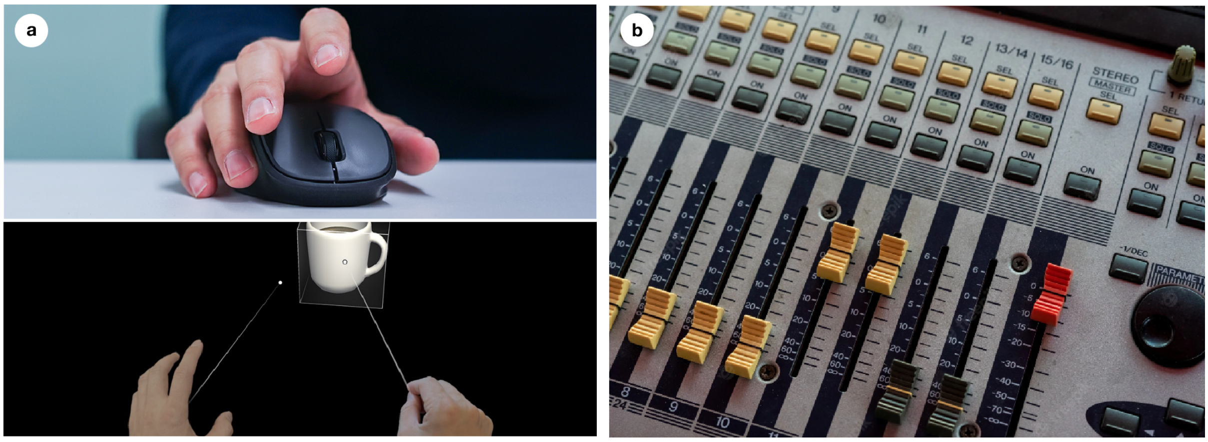


Figure 2.4: Time Multiplexing and Space Multiplexing Input
(a) Time multiplexing: one device is used to control different functions at different points in time like mouse and raycasting, (b) Space multiplexing: each function to be controlled has a dedicated transducer like audio mixing console [18]

Particularly, compared to traditional GUI input devices like a mouse - Time multiplexed input (Figure 2.4a), spatially mapped controls (Space multiplexed input like Figure 2.4b) enable users to engage in more perceptual actions, reducing mental effort [19]. In this regard, the impact of virtual reality and augmented reality interfaces on the creative design process is discussed in Tilanka et al.[12]. Additionally, Alissa N. et al.[5] demonstrate the efficiency and cognitive motor strategies enabled by 3D manipulation and offline work. Based on these findings, our work aims to support creative authoring through realistic and natural interactions by transforming existing 2D user interfaces into everyday 3D objects. We extend previous research that compared the performance of 3D-represented control panels with 2D interfaces and investigate how this interface transforms user behavior and supports creativity in the immersive authoring process.

Specifically, our evaluation goes beyond previous studies that primarily focused on performance metrics of controls in virtual environments. Instead, we delve into the user experience during creative work processes with 3D-represented 2D interfaces, an area that has received relatively less exploration. While prior studies [28, 16, 17, 7] mainly quantitatively compared task completion times of mouse devices,

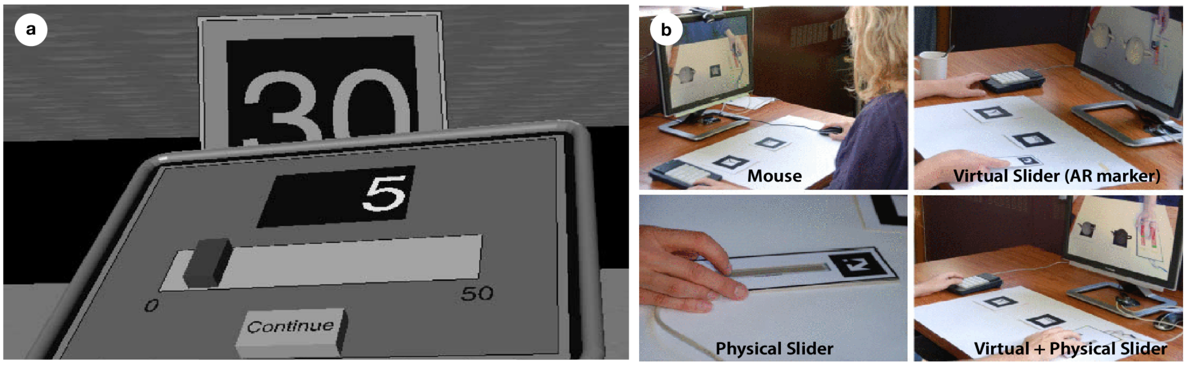


Figure 2.5: Previous Studies with Evaluation of Control Performance
(a) The effect of 3D widget representation and simulated surface constraints on interaction in virtual environments [28], (b)Evaluation of User Interfaces with Mouse, Physical and Virtual Slider [16]

physical and virtual sliders (Figure 2.5), our research investigates how that interaction in the interface influences the overall experience, particularly in tasks involving user creativity.

3.
FORMATIVE STUDY

Chapter 3. Formative Study

A formative study was conducted to clearly understand the user experience of creative working with virtual screens. The study aimed to understand the experience of users working in VR, discover the limitations of the current interface, and identify specific breakpoints of workflow. To achieve this, we utilized a contextual inquiry approach [24], which allows researchers to obtain users' vivid thoughts and behaviors during the work process.

3.1 Participants

To exclude factors arising from the lack of experience in operating VR or performing design tasks, participants were limited to those who met the following criteria: having previous VR experience and familiarity with bare-hand interaction of VR and design task performance. Accordingly, the 4 participants (2 Males, 2 Females, Average age = 23.0, SD = 0.8) were recruited as in Table 3.1. Most of them had more than 10 previous VR experiences and at least 2 years of design experience.

Table 3.1: Demographic Information of Formative Study Participants

Participant Code	**Gender**	**Age**	**VR Experience (times)**	**Design Experience (years)**
F1	Female	22	≥10 times	4 years
F2	Female	23	4∼10 times	4 years
F3	Male	24	≥10 times	5 years
F4	Male	23	≥10 times	2 years

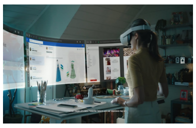
3.2 Setup and Procedure

To select the interface for this formative study, we analyzed existing applications that support virtual desktop work in advance (see Table 3.2). We investigated Oculus Browser[1], vSpatial[2], Horizon Workrooms[3], Immersed[4], and Virtual Desktop[5], and selected apps that support private workspace, multiple screens and bare-handed interaction. Therefore, Oculus Browser (fixed screen layout) and Immersed (free screen layout) were used in the study according to the screen layout type.

Prior to this formative study, a brief pilot test was conducted to adjust the task difficulty level. To investigate creative work experience in VR, a simple interface design task was initially planned. However, due to the limitations of existing apps available for the study, a simpler design task (creating a mood board) was selected. The initial plan to observe bare hands interaction without additional equipment was also modified due to the technical limitations of the current interface. Instead, participants were

[1] https://www.oculus.com/experiences/quest/1916519981771802/
[2] https://www.vspatial.com/
[3] https://forwork.meta.com/horizon-workrooms/
[4] https://immersed.com/
[5] https://www.vrdesktop.net/

Table 3.2: Applications Supporting Virtual Desktop Work

	Oculus Browser	**vSpatial**	**Workrooms**	**Immersed**	**Virtual Desktop**
Images					
Featured function	private workspace	private workspace, collaboration	collaboration	private workspace, collaboration	entertainment
Screen layout	fixed screen layout			free screen layout	

instructed to use both raycasting and mouse input, as required, to allow for flexibility in performing the tasks. This decision was made to better align with the study's goal of investigating the creative design process in a virtual environment, despite the technical constraints of the available applications.

To begin, participants received a brief explanation of the study and were loaded into one of the two apps. They had approximately 5 minutes to set up the workspace and become familiar with the interface before the task. Participants were requested to search and watch videos and perform multi-screen tasks to create a mood board. They were also asked to think out loud during the process. They could interact with the virtual screen by raycasting, mouse, and keyboard to complete the task. After about 10 to 15 minutes of the task, they took a 5-minute break and then repeated the same process in the other app environment. Afterward, a brief semi-structured interview was conducted to gather participants' feedback on their experiences. Their view was mirrored and recorded to observe task performance on the researcher's computer. Their behavior and interviews were also recorded for analysis.

3.3 Results

3.3.1 Sequence Model

To understand the workflow and identify potential obstacles in performing creative work with bare hands in a virtual environment, we created a sequence model (Figure 3.1) based on the observed behaviors. This model illustrates participants' intentions, actions, and breakpoints. Typically, participants repeatedly switched between the reference and task screens during the design process. They also used the raycasting and mouse interchangeably during this process. Therefore, the sequence model is constructed in a nested loop format.

The interruptions breaking workflow were primarily triggered by the interaction that does not sufficiently consider the creative work characteristics. Participants had to switch between two inputs due to the inconvenience of both raycasting and mouse. This significantly impaired task immersion since the creative work needs frequent access to specific controls. The breakpoints were identified as follows:

- (Raycasting) Difficulty pointing to small elements in the control panel accurately
- (Raycasting) Arm fatigue caused by continuous in-air input
- (Mouse) Inconvenience of navigating a long path to other virtual screen GUI elements
- (Mouse) Inconvenience of the mouse losing track in spatial interaction
- (Design process) Repetitive hand and gaze movements caused by frequently accessed elements

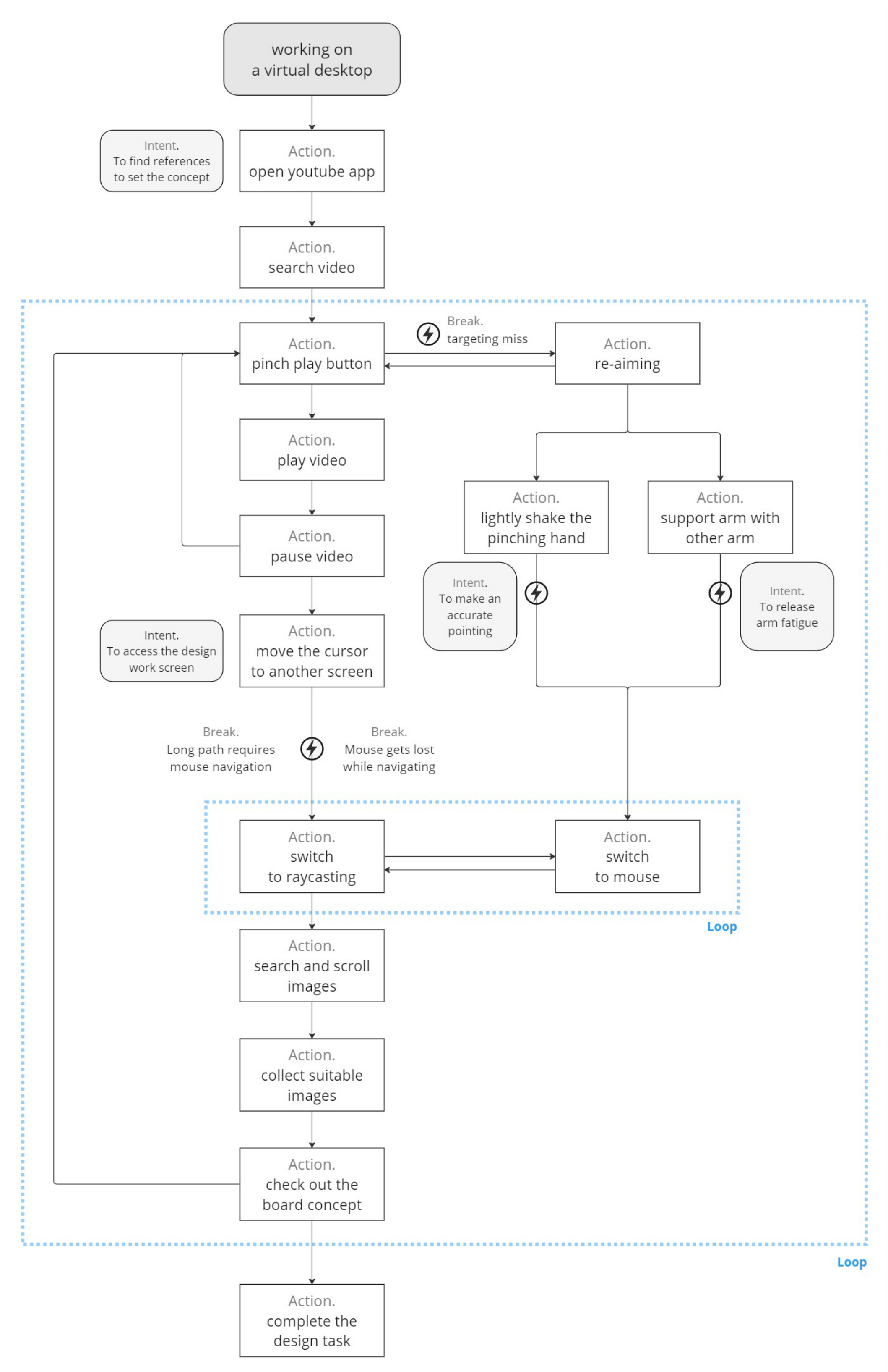


Figure 3.1: Sequence Model demonstrating workflow, action, intention, and breakpoints in design tasks with virtual desktop and bare-hand interaction

3.3.2 Qualitative Findings

Thematic analysis [8] was conducted to extract meaningful and inspiring insights by synthesizing interview results and observed behaviors. The recorded interview data were transcribed, and codes were applied to the quotes for collection. Similarly, the observed behaviors were also coded and collected based on the significant behaviors identified during sequence modeling. Subsequently, these data were grouped by theme to summarize the insights.

Although raycasting and mouse inputs are widely used in VR and the real world respectively, they cause discomfort when used for design tasks in virtual reality. To clarify the reasons behind this, we first categorized the characteristics of the creative work and working in VR. Then, we examined how the combination of these characteristics produces pain points.

Characteristics of the creative work

D1. Utilizes multiple screens such as reference and task windows

D2. Requires interaction with a GUI that has many densely packed elements

D3. Requires repetitive access to certain control functions

D4. Includes various types of controls such as buttons, sliders, etc.

Characteristics of working in a virtual environment

V1. Typically uses a larger virtual screen than in reality to increase immersion

V2. Uses raycasting methods to interact with distant objects.

Pain-points of creative work with virtual screen

P1. Generation of repetitive and lengthy movements of the hands and gazes (D1+D3+V1)

The creative work process typically involves repetitive control of specific elements. In this study, participants repeatedly had to access a video's play/pause button, which required them to navigate long paths across multiple screens. Especially in virtual screens, which are generally larger than physical ones to enhance immersion, they must travel longer distances. Therefore, participants tended to use raycasting instead of a mouse when repeatedly accessing functions on other screens. (F4) *"Using a mouse to traverse such a wide space is uncomfortable, so I just used my hand to pinch the screen directly. However, using my hand was not completely comfortable either because I had to constantly move between screens."*

P2. Physical fatigue due to fine manipulation required for control panels (D2+V2)

Interfaces with many controllable elements, like control panels, require fine manipulation for users. Since raycasting requires targeting a small area through in-air gestures, users are required to exert more physical effort. During the study session, participants' behavior, such as using another hand to support the arm or switching to a mouse, was observed. One participant said they switched to using a mouse because they needed haptic feedback for fine manipulation. (F1) *"When the buttons are small, raycasting often results in inaccurate targeting. Since the mouse has haptic feedback and can move smoothly over the surface, it was more convenient to use it when manipulating small elements."* In particular, this formative study was conducted with a relatively simple design task of creating a mood board. Still, if more complex tasks are involved, they may require more control panel manipulation, which could exacerbate this issue.

P3. Distracted attention by cognitively awkward indirect manipulation (D4 + V2)

Raycasting is a unique interaction method in VR that does not exist in reality. Controlling various forms of manipulation, such as buttons and sliders, through raycasting, which is disconnected from reality, caused participants to experience cognitive awkwardness and discomfort. (F2) *"I felt uncomfortable and frustrated with performing tasks using the raycasting method."* In particular, this caused participants to focus more on adjusting the interaction rather than the task itself, thus interfering with immersion. (F1) *"I ended up focusing more on controlling the gesture I was making rather than the task I was supposed to do."*

In summary, we found that while raycasting and mouse input may be suitable for simple tasks, they are often cumbersome for creative work in virtual environments. The combination of the virtual environment's large canvas and the control panels with different types of manipulation required for creative work creates discomfort. This led to a need for a new interface design that takes into account the characteristics of creative work to alleviate cognitive and physical fatigue. Providing appropriate interfaces to support such tasks can help users immerse themselves in creative work in virtual environments.

4.
DESK CONSOLE INTERFACE

Design Concept

Interaction Design

Implementation

Chapter 4. Desk Console Interface

This section focuses on addressing the question of "How can we design an immersive authoring interface that enables intuitive interaction with screen UI while ensuring both stability and natural operation." To answer the question, the thesis introduces the Desk Console interface. This section provides an overview of the design concept and explains the interaction design process and implementation details.

4.1 Design Concept

Based on the findings discussed in the previous sections on Related Works and Formative Study, we aimed to enhance the raycasting method by involving a more direct manipulation approach that closely resembles real-world interactions. The objective was to minimize cognitive awkwardness by emulating reality. Given that the authoring process required not only natural and abundant interactions but also precise and stable manipulation, we recognized the importance of providing physical support. In this regard, we identified the desk as an ideal passive haptic medium, a common and essential object in personal workspaces. Its suitability stemmed from its ability to allow comfortable positioning of the eyes and arms within their respective zones, akin to the traditional desktop setup. This initial design concept is illustrated in Figure 4.1.

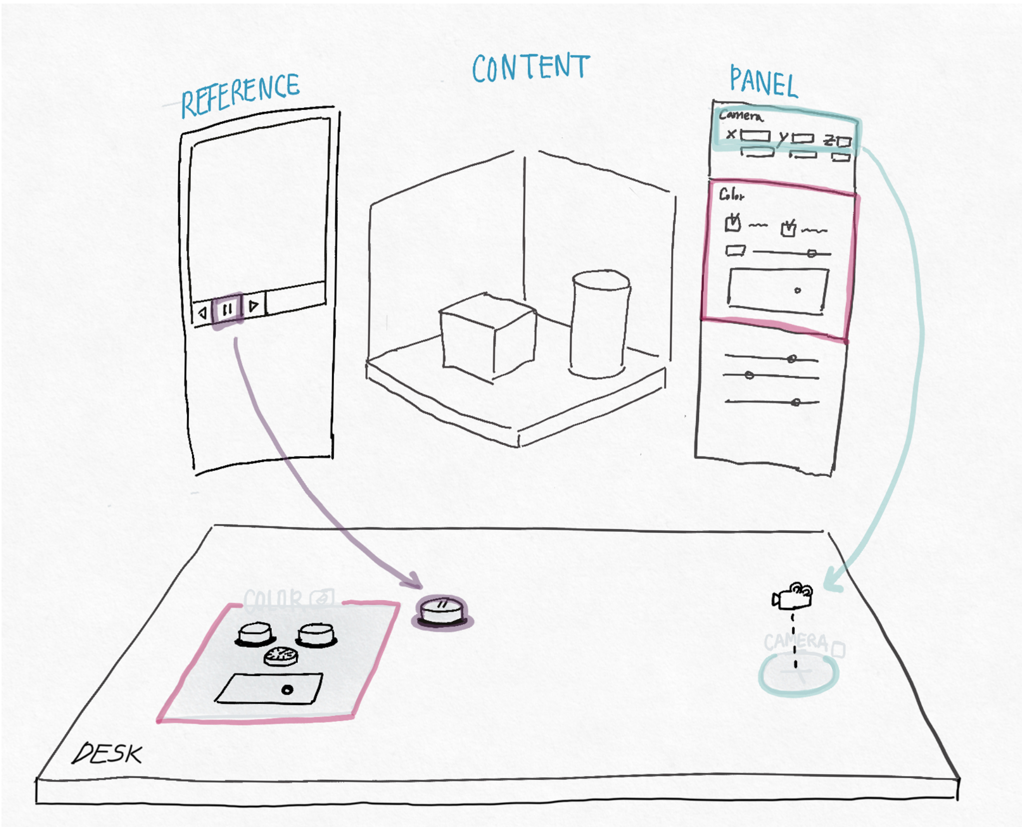


Figure 4.1: Initial design concept sketch

Furthermore, our exploration focused on leveraging the tactile sensation of the hand and the desk surface to facilitate natural interactions (Figure 4.2). Throughout this process, we recognized the need for a more systematic approach to interaction design to achieve scalability and flexibility. Consequently, we defined clear interactions by categorizing existing UI elements and establishing design principles. The subsequent section provides a comprehensive overview of the detailed interaction design process.

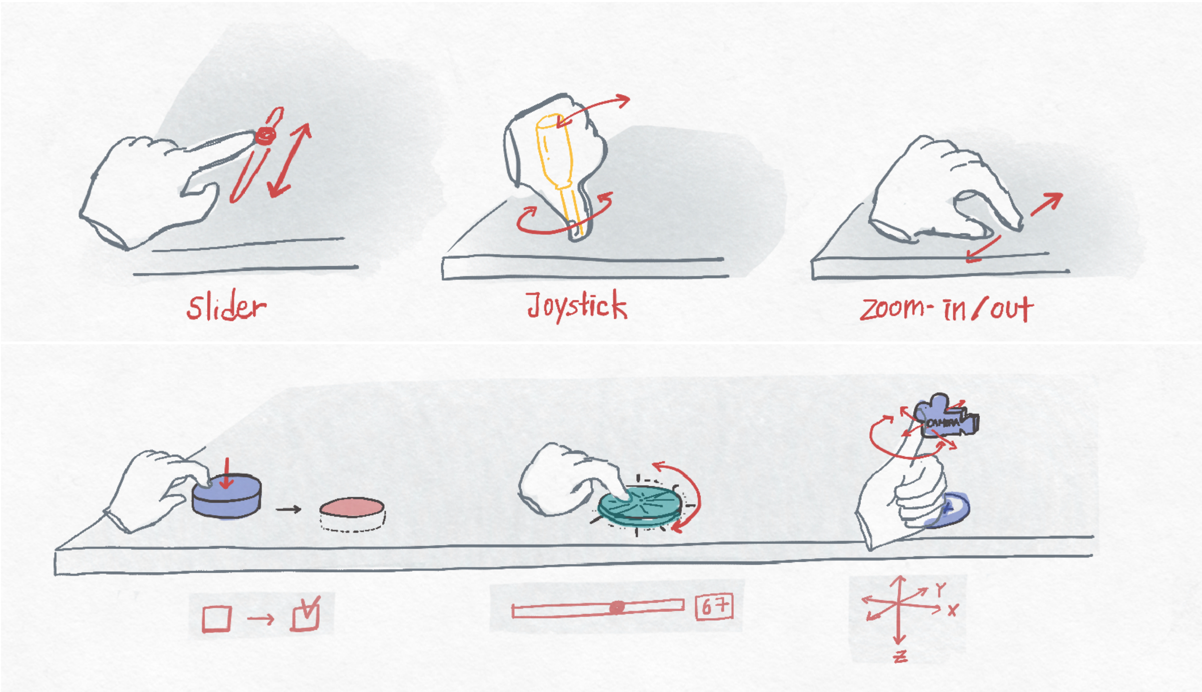


Figure 4.2: Initial interaction exploration sketch

4.2 Interaction Design

4.2.1 Categorize UI Elements of Creative Tools

Figure 4.3: Unity[1]'s interface. The control panel appears on the right as a window called Inspector.

As a preliminary step in transitioning the existing 2D GUI into a 3D representation, we conducted a classification of input types used in the control panel interface to identify the main UI elements. To accomplish this, we examined the interfaces of popular design tools, such as Adobe Creative Suite[2], commonly utilized in creative work. Additionally, we mainly referenced the editor windows of scene development tools like Unity[3] and Unreal[4] (see Figure 4.3 for an example, Unity's Inspector window).

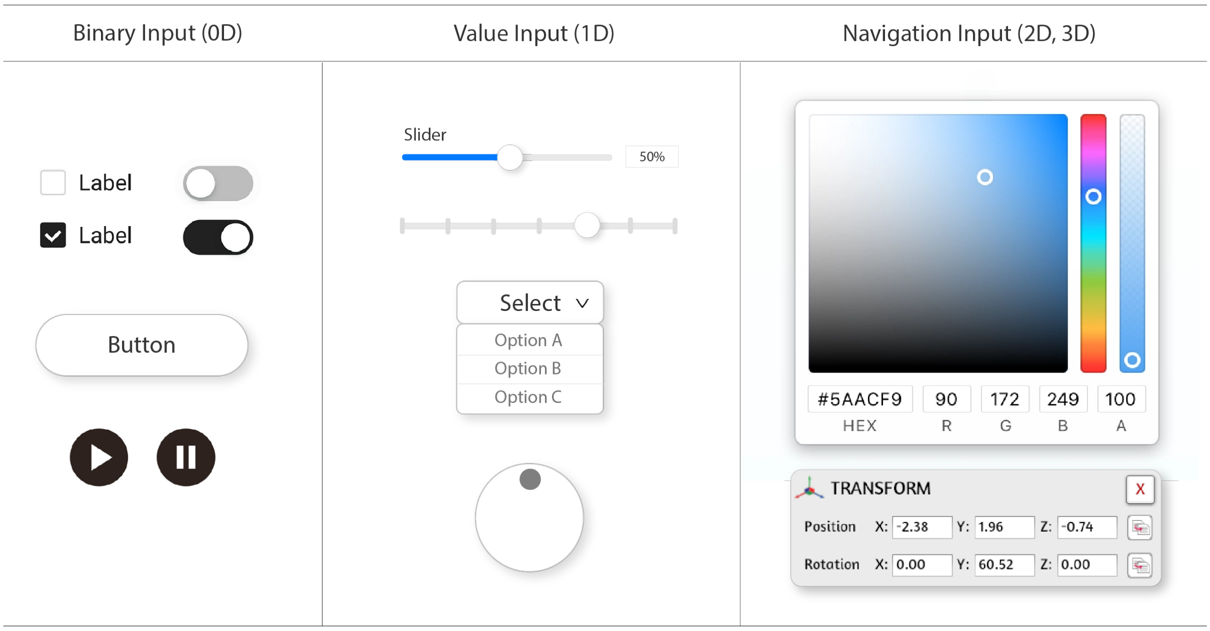


Figure 4.4: Categorized UI elements according to input resolution

To handle the complexity of existing control panels, we categorized them based on common input methods. This categorization was guided by references exploring the design space of input devices [9, 10, 30]. The control panels' UI elements found in these creative tools were categorized into three primary input methods, as depicted in Figure 4.4.

1. **Binary Input (Dot; Zero-dimension; 0D)**

   This input type encompasses button-like interactions, including toggle buttons and checkboxes. Examples include the play/pause button on YouTube or checkboxes used to activate or deactivate specific objects or scripts in Unity. The resolution of this input is two since it has two states.

2. **Value Input (Line; One-dimension; 1D)**

   This category involves controls used for inputting values along a linear axis. It includes sliders and dials used for continuous value input, as well as drop-down menus for segmented value input. The resolution of this Value Input is more than three.

3. **Navigation Input (Plane or Cube; Two or Three-dimension; 2D, 3D)**

   Here, we expand the Value Input to make two-dimensional (2D) and three-dimensional (3D) input category. A notable example is the Color Picker, allowing users to select colors from a rectangular frame. In the case of 3D navigation input, x, y, and z values are used to control screen or object movement. These inputs can be seen as a 3D input itself or a combination of three 1D inputs.

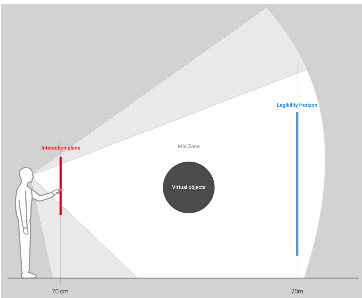
[2] https://www.adobe.com/creativecloud
[3] https://unity.com
[4] https://www.unrealengine.com

While this classification may not encompass all possible UI controls, we aimed to comprehensively define the most commonly used UI elements to ensure high flexibility and adaptability. Grouping UI elements based on their input type serves as a foundation for designing in a flexible and scalable manner, allowing for streamlined transitions from 2D GUI interactions to 3D representation manipulations without the need for redesigning from scratch each time.

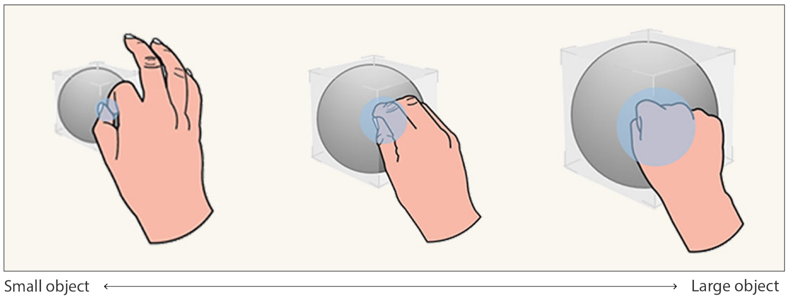
4.2.2 Define Interaction Design Consideration

AR/VR Interaction Design Heuristic and Principle

Designing for AR and VR environments requires considering unique principles and heuristics to create interfaces that are intuitive and user-friendly. Unlike traditional flat interfaces found in smartphones and computers, AR and VR demand tailored design approaches that leverage the spatial nature of these immersive technologies. Recognizing this need, industry leaders such as Microsoft [33] and Ultraleap [40] have developed guidelines specifically addressing spatial factors in AR/VR design. Drawing inspiration from these guidelines [33, 40, 36, 1], our interaction and interface design incorporated the following key principles.



(a) three interaction planes [36]



(b) Instinctual gestures according to object size [33]

Figure 4.5: Illustration of Spatial and Gesture Interaction Design Principles in AR/VR

DP1. Placement considering Spatial Design Zone: Consider placing content in virtual and augmented environments based on spatial hierarchy. Direct interactable elements should be within the user's arm's reach, within the Interaction Plane (50cm to 70cm), while indirect interactable content should generally be no more than 20 meters away, typically around 2m. (Figure 4.5a)

DP2. Direct Manipulation with Instinctual Gestures: Utilize direct manipulation, where users interact closely with objects using their hands, resembling real-world interactions. Design UI affordances to support instinctual gestures, such as a two-finger pinch for grabbing small objects or utilizing larger finger and hand areas for larger objects. (Figure 4.5b)

DP3. Familiar UI Patterns in Spatial UI: Implement buttons and controls in a manner similar to 2D interface design, considering spatial design. This approach allows users to easily form mental models and navigate the interface more intuitively.

DP4. Importance of Audio and Visual Cues: In AR/VR environments, audio and visual cues play a crucial role in helping users adapt to unfamiliar spaces. Provide immediate audio feedback and clear visual cues to assist users in understanding the state of interactions and increasing their confidence.

Creative Console Consideration

Figure 4.6: Digital Creator Console. (Left) Tourbox, (Right) Monogram Creative Console

Referring to existing physical Creative Console devices(Tourbox[5] and Monogram Creative Console[6]), the following considerations were taken into account when determining the operation and shape of the 3D-represented interface. These considerations ensure that the 3D representation of the interface aligns with the usability and functionality observed in existing physical Creative Console devices.

CC1. Simplicity for Blind Operation: The operation should be relatively simple, allowing users to perform tasks without confirming each action visually. Users tend to naturally return their attention to the content in the center of the screen after selecting a button.

CC2. One-Handed Operation: Each control should be designed to be operated with one hand, enabling users to utilize their other hand for additional controls and enhancing overall productivity.

CC3. Simple Form with Affordance: The form of the controls should be simple and intuitive, providing clear affordance that allows users to easily grasp the intended function.

Table 4.1: Defined Interaction Design Consideration

Reference	Code	Category	Principle and consideration
AR/VR Design Guideline	PD1	Placement	Consider spatial zoning when placing content
	PD2	Manipulation	Design direct manipulation with instinctual gestures
	PD3	Form	Adopt Familiar user interface(UI) Patterns
	PD4	Cue	Provide sufficient audio and visual cues for interaction
Exsiting Creative Console Interface	CC1	Manipulation	Maintain simplicity for blind operation
	CC2	Manipulation	Design for one-handed operation
	CC3	Form	Design simple form with clear affordances

In summary, the design considerations discussed in Table 4.1 were informed by AR/VR design guidelines and insights from existing physical creative console devices. These references served as valuable resources in shaping the design of the desk console interface. By leveraging these insights, our goal was to develop an interface that effectively combines the best practices from AR/VR design and the functionality of physical consoles, resulting in an intuitive and efficient user experience.

[5] https://www.tourboxtech.com/
[6] https://monogramcc.com/

4.2.3 Desk Console Interaction Design

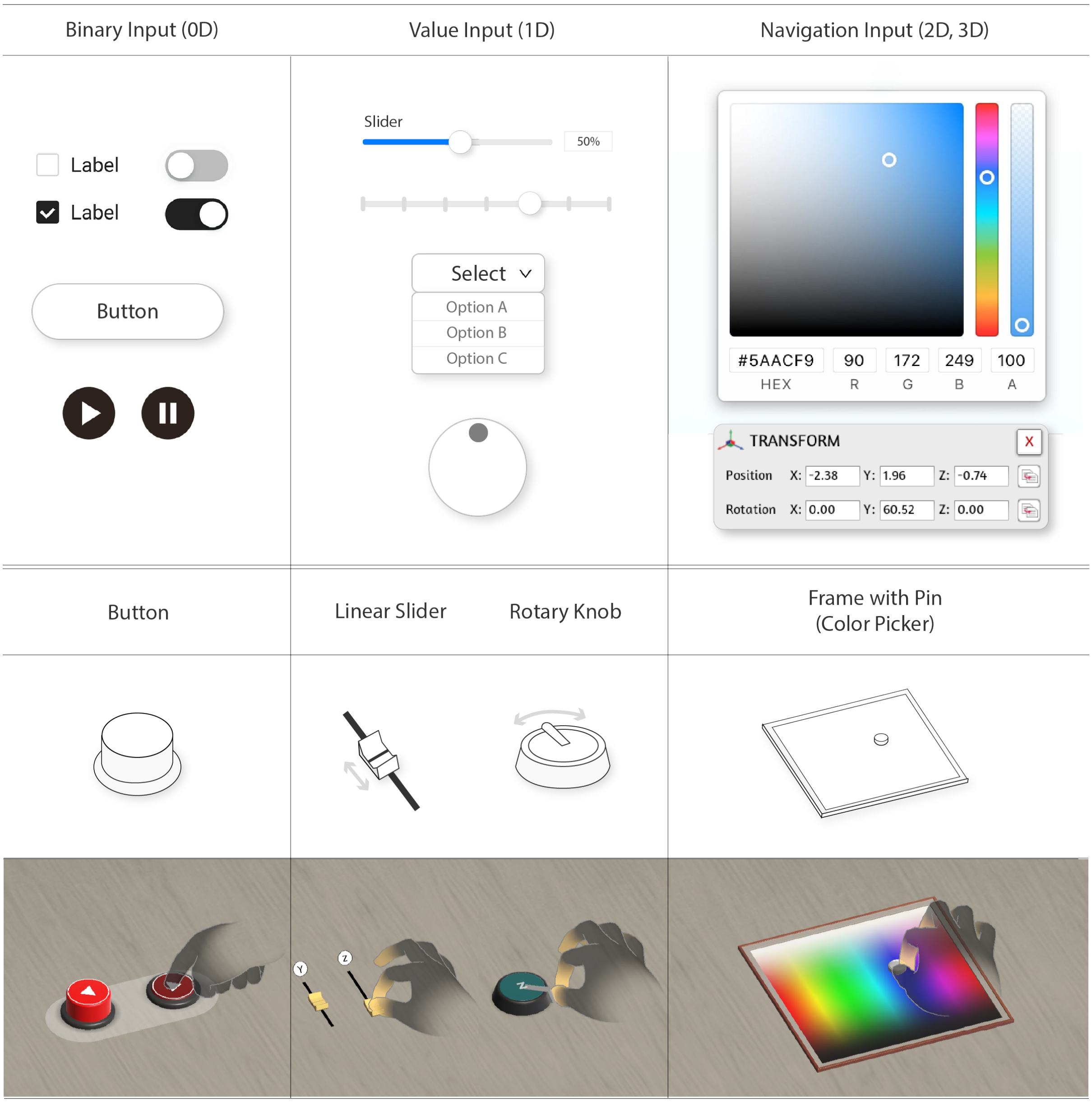


Figure 4.7: 3D Representation and Interaction Based on UI Input Type

The UI elements were transformed into 3D representations based on the input resolution, as illustrated in Figure 4.7. Specifically, Binary Input was represented as Buttons, Value Input as Sliders, and Navigation Input as Frame with Pin. Before delving into the specific details of each element, let's first discuss the overall design considerations (Table 4.2)

For placement, considering the spatial zone of VR (PD1), objects to be directly operated were positioned within the arm-reachable zone range of 50 to 70 cm from the user. The screen and contents were placed in a zone beyond 70 cm but within 2 meters, ensuring optimal visibility. For the form, we aimed to maintain the familiarity of existing UI patterns while ensuring that the shapes resembled familiar real-world objects, allowing users to easily infer their functions (PD3, CC3). The controls were designed to be operated with a single hand, without the need for constant eye contact. By aligning the interaction

Table 4.2: Design Considerations Applied to Desk Console

Category	**Code**	**Applied to Desk Console**
Placement	PD1	Direct Manipulation Object: Arm reachable zone (50-70cm) Screen and Contents: Virtual object zone (70-200cm) for visibility
Form	PD3+CC3	Incorporated familiar UI patterns and real-world object shapes for efficiently recognizable interface
Manipulation	PD2+CC1 +CC2	Designed single-handed controls without constant eye contact Used instinctual and real-world interactions for a seamless experience
Cue	CC3	Sound cue: Used sounds mimic real-world counterparts Visual cue: Made fingertip color change for confident interaction

with instinctual behaviors and mimicking real-world interactions, we aimed to create a seamless and immersive experience (PD2, CC1, CC2). Additionally, clear audio feedback was incorporated into the design, with each control producing sounds akin to their real-world counterparts. (e.g., buttons hitting sound) For visual feedback, the color turns dark when the button is pressed to let the user know that the execution was successful. Furthermore, the Slider and Frame with Pin were designed to provide visual cues to users, as their fingertips' color would change to yellow when properly interacting with these elements, instilling confidence (PD4).

Button

Binary inputs in the UI are translated into physical buttons in the real world. Users can interact with these buttons by either pressing them with a finger or striking them with a hand. The button's depressed surface matches the desk's surface, providing users with a tactile sense of impact upon pressing. In Figure 4.8, an example application shows a video play/pause UI displayed as a button on the desk. The graphic above the button dynamically changes with each press, providing clear visual feedback on the button's state. In the case of checkbox-type buttons, when the UI is checked, the button also exhibits a slight depression.

Slider

Value inputs in the UI take the form of sliders, akin to audio mixers. Adhering to the principles of PP2, the interaction simulates the act of grasping a small object, utilizing a natural pinch gesture. Similarly, the virtual slider aligns with the physical desk surface, enabling users to slide their hands back and forth across the desk. Figure 4.8 demonstrates vertical and horizontal 3D sliders on the desk considering the direction of the UI slider (PP3). For inputting infinite values, a rotary knob is employed. Although not depicted in the example interface, discrete sliders were also considered for elements like drop-down menus.

Frame with Pin

Navigation inputs in the UI are represented by a pin placed on the small frames. Like the slider, these interactions involve pinching gestures, enabling users to navigate color within the frame while perceiving the physical desk surface.

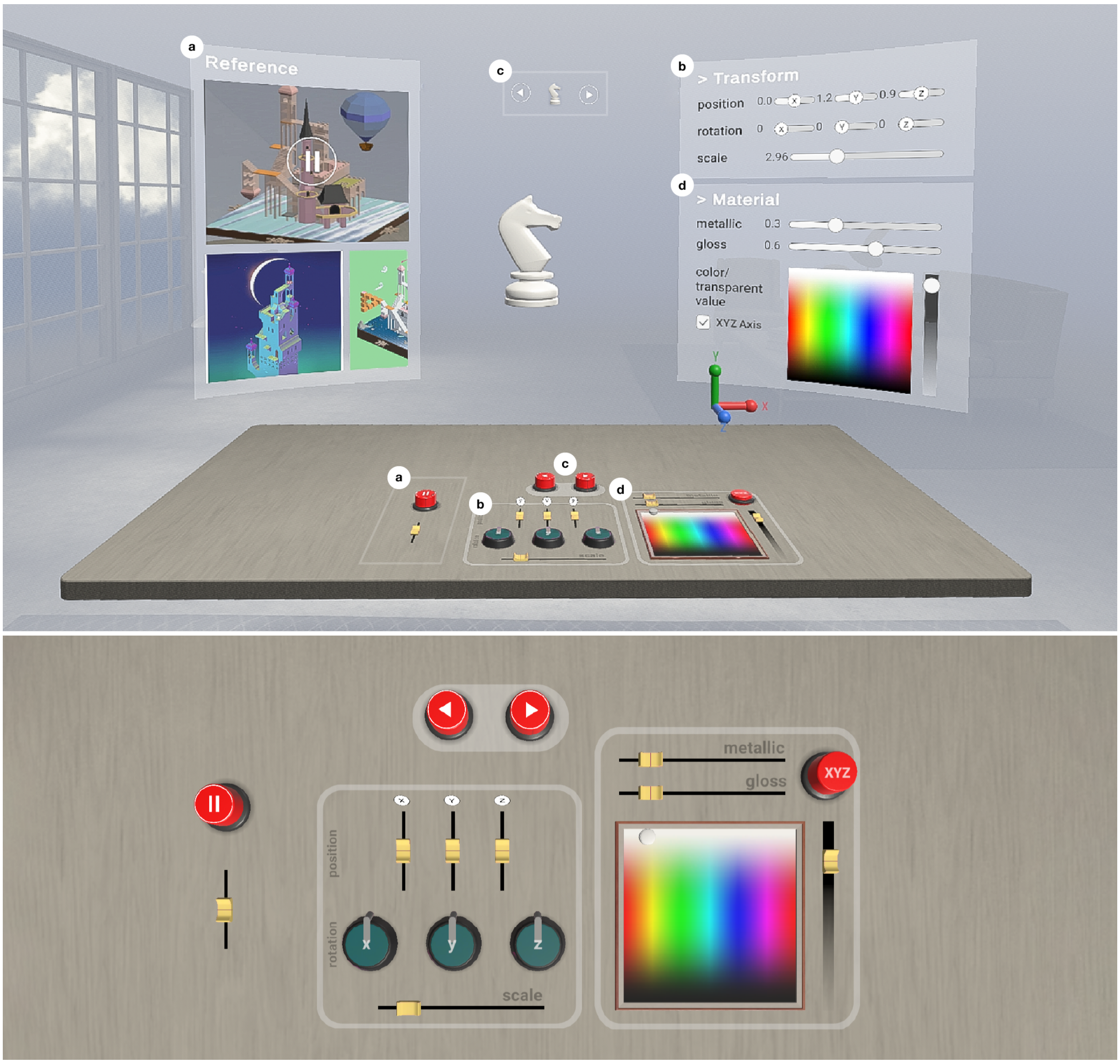


Figure 4.8: (Top) Overview of the Desk Console interface, illustrating the alignment between the screen UI and their corresponding physical counterparts on the desk. (Bottom) Top view of the Desk Console interface

4.3 Implementation

The Desk Console interface was implemented in the VR environment to control the environment and variables systematically. An Oculus Quest 2 device capable of real-time hand tracking with a built-in camera was utilized as the VR head-mounted display (HMD) device. The software was developed using Unity Game Engine (version 2020.3.33f1), and the hand tracking and interaction functionality was implemented using the Oculus Interaction SDK (version 49.0).

The workspace was designed to minimize distractions and provide users with a focused work environment. The built-in minimalistic Room from the Oculus SDK was utilized for this purpose. By matching the virtual desk included in this Room with the physical desk in the real world, passive haptic is provided during manipulation.

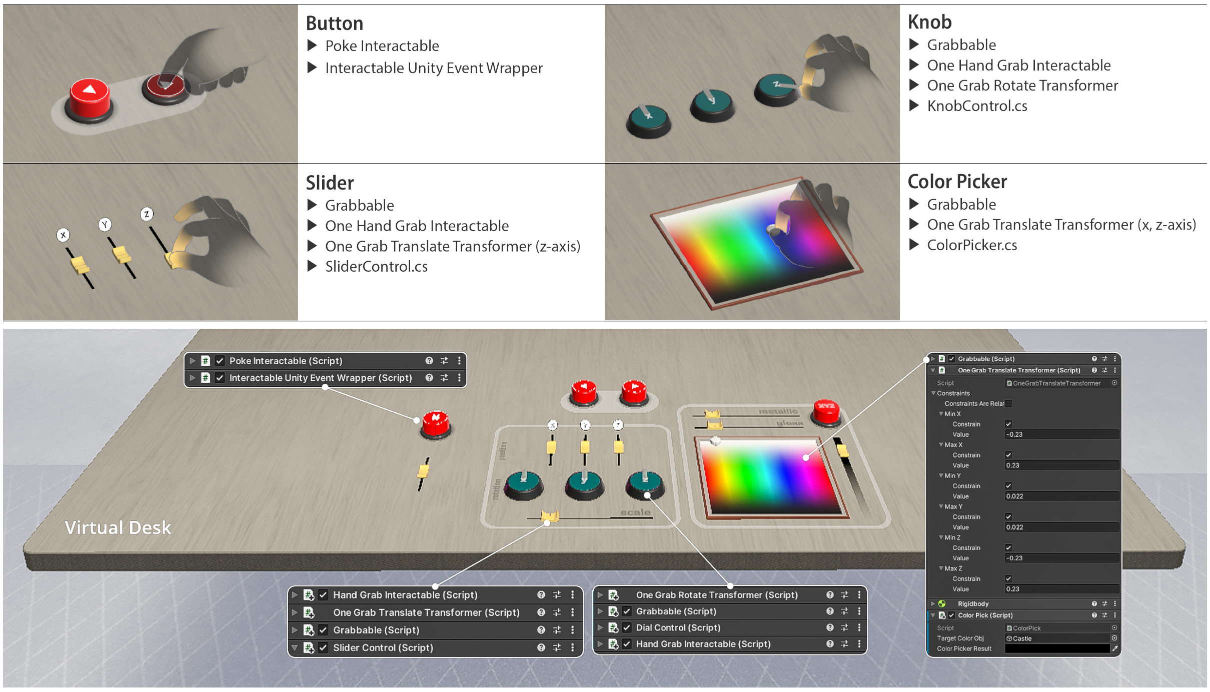


Figure 4.9: Scripts and Oculus SDK features used for each control

Figure 4.9 illustrates the scripts used for each control in the Desk Console interface. The button control utilizes Poke Interaction[7], simulating the experience of pressing a physical button. When the user interacts with the button, their finger touches the surface of the desk, providing a tactile sensation. The slider, knob, and color picker controls are designed with the Grabbable[8] function, allowing users to manipulate them by grabbing and interacting with virtual objects. The slider and color picker use the Translate Transformer function for linear and two-dimensional movement, respectively, while the knob employs the Rotate Transformer function for rotational control. The color picker determines the selected color by detecting the intersection of a ray projected from the pin with the color table texture. These interaction mechanisms enable intuitive and realistic control, mimicking physical manipulation in the virtual environment.

[7]https://developer.oculus.com/documentation/unity/unity-isdk-poke-interaction/

[8]https://developer.oculus.com/documentation/unity/unity-isdk-grabbable/

5.
USER STUDY

Chapter 5. User Study

We conducted a user study to verify whether the Desk Console interface effectively supports creative work using a control panel in a virtual environment. The objective is to investigate how the interface enhances user experience compared to existing methods and how it changes the content creation process. To achieve this, we designed the user study using a within-subjects approach widely used in human-computer interaction research to compare the newly proposed system with the existing system [29].

5.1 Participants

The user study was conducted with 14 participants (Table 5.1; 7 males, 7 females, mean age = 25.4, SD=2.8). Participants were recruited based on the following criteria through a pre-questionnaire using Google Forms: (1) previous VR experience and no severe VR sickness, (2) familiarity with 3D tool interfaces, (3) previous 3D design experience. Overall, most participants had more than 10 times of VR experiences, so they were familiar with virtual environments and had experience in design and development using 3D tools such as Unity and Unreal. Additionally, most had experience producing 3D content, and three had professional experience in the industry.

5.2 Study Configurations

5.2.1 Baseline Design

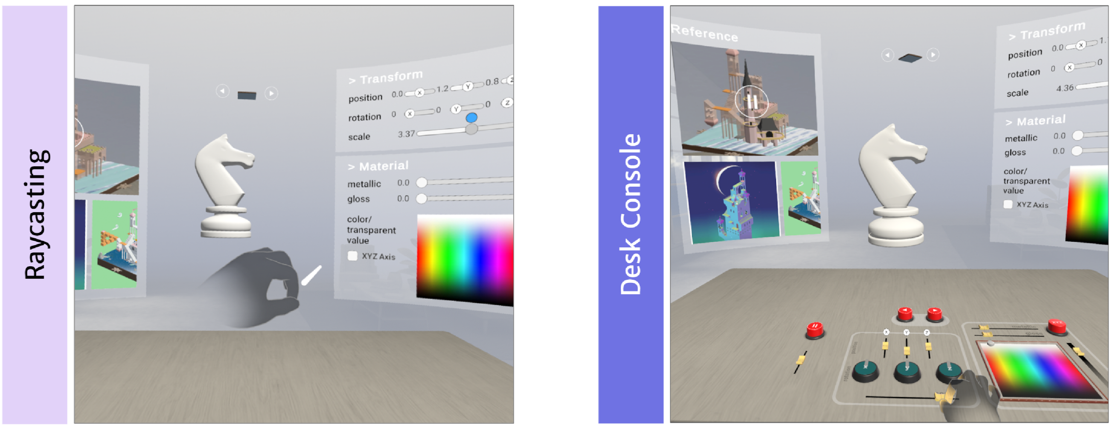


Figure 5.1: Raycasting (baseline) and Desk Console interface used in this user study

To better understand the user experience of the designed user interface, I have chosen Raycasting as the baseline condition for a user study (Figure 5.1). Raycasting is a commonly used method for interacting with screens in virtual environments. This baseline condition was developed using the Oculus Interaction SDK [1]'s Raycasting function executed by pinch gesture, similar to exactly the same as when interacting with the menu of Oculus Quest. When the user raises their hand towards the screen, a pointer appears,

[1] https://developer.oculus.com/documentation/unity/unity-isdk-interaction-sdk-overview/

Table 5.1: Demographic Information of User Study Participants

Code	Gender	Age	VR Exp.	3D Tool Used	3D Design Exp.	Study Order
P1	Male	29	4∼10 times	Unreal, Rhino, Sketchup	Architectural modeling (3-4 years)	ray/desk
P2	Male	25	≥10 times	Unreal, CAD, Blender	Digital twin design, product design (6 years)	desk/ray
P3	Male	29	≥10 times	Unreal, Cinema4D	Professional exp. as a 3D artist (5 year)	ray/desk
P4	Male	24	1∼3 times	-	-	ray/desk
P5	Female	25	≥10 times	Unity, Fusion360	VR environment production	desk/ray
P6	Female	21	≥10 times	Unity, Fusion360	VR environment production	ray/desk
P7	Female	23	≥10 times	Unity, Maya	VR game design, development	desk/ray
P8	Male	24	≥10 times	Unreal, Maya, Cinema4D	Game scene design, development	ray/desk
P9	Female	28	1∼3 times	Unity	Professional exp. game development (3 years)	desk/ray
P10	Male	29	≥10 times	Unity, Rhino	Architectural modeling, VR development	ray/desk
P11	Female	24	≥10 times	Unity	VR design, development for research	ray/desk
P12	Female	29	≥10 times	Unity, Unreal, Cryengine	Professional exp. game modeling (3 years)	desk/ray
P13	Female	22	1∼3 times	Blender, Rhino, Fusion360	3D modeling, graphic design	desk/ray
P14	Male	24	≥10 times	Unity	VR design,development for research	desk/ray

and when they pinch their hand, the click is registered. A sound effect is also added for selecting and releasing to provide more precise feedback. The virtual screen is designed with a curved shape at a distance, similar to the Oculus Browser App screen. From now on, we refer to this baseline condition as Raycasting.

5.2.2 Task Design

To investigate the impact of the interface on creativity support, the user study task was designed as an open-ended task that can include participants' creative processes. Scene Level Design was chosen as the task domain since it requires frequent VR testing to verify the size and color in the virtual environment. The goal of the task is to create a game scene content with a specific concept by adjusting elements of the given assets.

The GUI is structured similarly to the commonly used 3D authoring tools such as Unity and Unreal. The control panel is placed on the right side where the content is displayed, just like the default interface of existing apps. Referring to the interviews with a media artist with over five years of professional experience and scene-building process videos, we designed the control panel with the most frequently used Transform and Material Panels. Each panel allows participants to adjust the position (x, y, z), rotation (x, y, z), scale, metallic, gloss, transparency, and color values of Assets. In addition, to make it easy to understand x, y, and z in the spatial work, a function that displays the 3D coordinate system was designed with a toggle button. Considering the actual work process, we placed a Reference Screen that provides concept images that participants can refer to. Above the 3D content, the Object Screen lets participants quickly check and add manipulable 3D assets. The currently displayed asset in the center of the Object Panel can be manipulated through the control panel, and the left and right arrows can switch to other assets. For the Assets, we composed five like in Figure 5.2. To prompt participants to try various concepts and moods, we chose abstract objects such as a castle, hot air balloons, and chess pieces that can imagine relatively diverse positions.

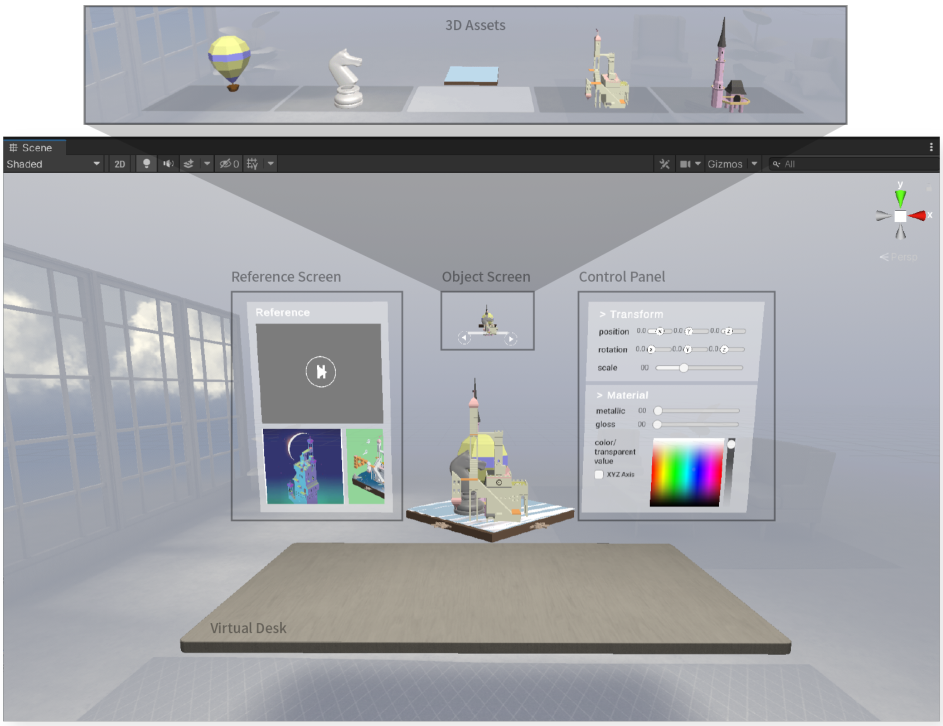


Figure 5.2: Scene overview of the base interface used in the user study. From left to right: reference screen, object screen, and control panel. Above: 3D assets utilized in the study. (Note that the curved shape of the screen is not reflected in this game scene capture.)

5.2.3 Procedure

The study was conducted with participants comfortably seated in front of an empty desk in a quiet indoor environment. Prior to beginning the study, participants completed a consent form, which included agreeing to be filmed and recorded. Next, they were provided with a brief explanation of the experiment task and how to operate the interface, and were then loaded into one of two interface tutorial scenes.

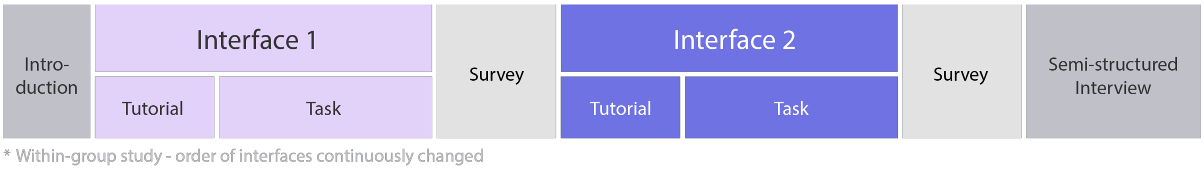


Figure 5.3: Structure and procedure of user study

Considering that the height of each participant varies, the researcher adjusted the virtual environment's desk to match the actual desk height. After spending 3-5 minutes on the tutorial to learn the operation sufficiently, participants were moved to the main task scene.

Participants were tasked with modifying the transform and material elements of given assets in each interface scene to create one game content. They determined the scene concept by referring to a reference panel and were asked to perform the task with a different concept for each interface to minimize repetition. After completing the first task, participants took a 10-minute break without the HMD device. During this time, they were asked to rate their user experience on a survey and received a brief explanation of the next interface. The same process was repeated for the second interface, and the order in which the experimenters performed Raycasting and Desk Console was designed differently to consider order effects. After completing all tasks, participants conducted a semi-structured interview about their interface experience. On average, the user study was completed within 45 minutes.

5.3 Measure and Analysis

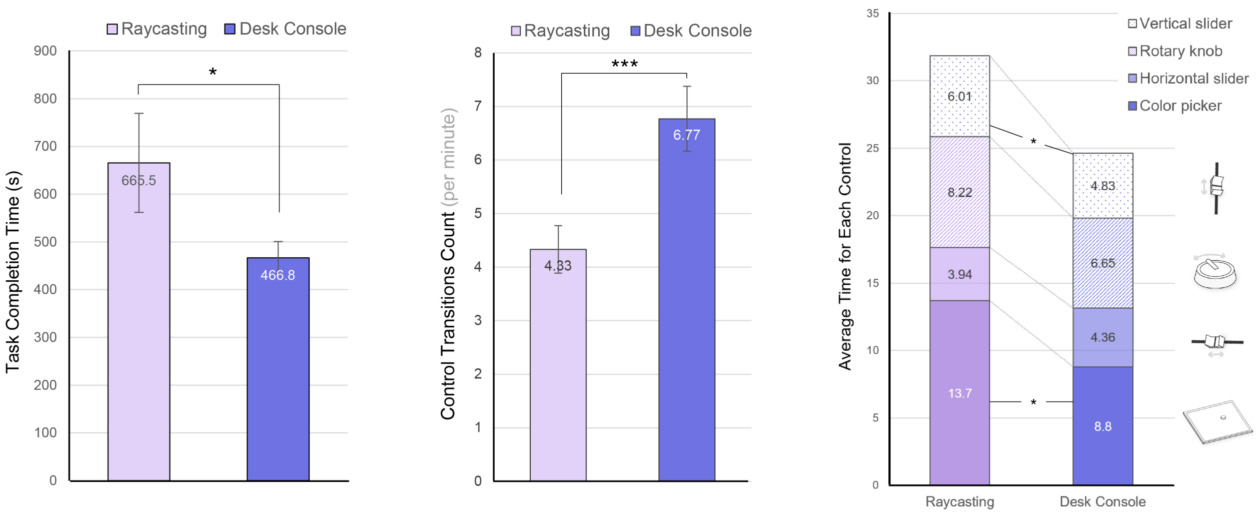
Following each study session, several types of data were collected, including recordings of the VR screen and Unity scene, behavior videos, log text files, and interview recordings. During the task, the VR view was mirrored and recorded with the unity recorder on the researcher's computer to ensure the participant's correct performance. The Unity scene was also recorded to analyze the overall performance process from a fixed view, and the participant's behavior was captured via camera for qualitative analysis. Their behavior log data was collected in a text file with timestamps during task performance.

To conduct a quantitative evaluation, the NASA Task Load Index (NASA TLX) [21] and Creative Support Index (CSI) [13] questionnaires were used. The NASA TLX was employed to measure the workload of the interface, and participants were asked to rate on a line with 21 marks between Very Low and Very High for six items (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration). The CSI was used to assess how interfaces supported creativity in different aspects, and participants scored five items (Exploration, Expressiveness, Enjoyment, Immersion, Worth Effort) excluding collaboration on a 7-point Likert scale. In addition, a semi-structured interview investigated the intention of observed behavior and overall interface usage experience during the experiment.

5.4 Results

We evaluated the Raycasting and Desk Console interfaces by analyzing the experiences of 14 users. We examined patterns and insights derived from their interactions with the interfaces. Quantitative data were assessed for normality, and statistical tests were conducted to compare the significance of the means. The details of the tests and their results are provided in Table 5.2. Additionally, we performed a thematic analysis [8] on the interview data. The insights from these interviews were used to support the quantitative evaluation results and inform the qualitative behavioral analysis. The creative results of 14 participants created by each interface can be found in Figure 5.7.

5.4.1 Performance Indicators Exploration



(a) Task Completion Time (b) Control Transitions Count (c) Average time for each control

Figure 5.4: Log data analysis results of Raycasting and Desk Console until task completion, with asterisks indicating the level of pair-wise significance (*p<.05, ***p<.001). The error bar indicates standard error.

Task Completion Time

The Task Completion Time (Figure 5.4a) refers to the average duration, measured in seconds, required to complete a task. In the context of an open-ended task, solely relying on completion time may not provide a comprehensive basis for comparing the performance of each interface. However, this metric can be supplemented and contextualized with other indicators discussed below. The task completion times for Raycasting and Desk Console were obtained and presented in Table 5.2 and Figure 5.4a. The results indicate that participants took an average of 665.5 seconds to complete the task using Raycasting, while they completed it in an average of 466.8 seconds using Desk Console. A comparison of the mean completion times revealed a statistically significant difference between the two interfaces (Wilcoxon Signed Ranks Test, p=.027* two-tailed). The analysis indicates that participants completed tasks significantly faster with Desk Console than with Raycasting, with an alpha level of 0.05.

Control Transitions per Minute

Control Transitions per Minute (Figure 5.4b) represents the number of transitions or switches between controls performed by the user during the task within a one-minute interval. For instance, if the user adjusts the scale slider after adjusting the position x slider, it counts as one transition. This provides insight into how effectively the interface supported users in utilizing a variety of controls to complete the task successfully. Figure 5.4b illustrates the average number of control transitions made by users in Raycasting and Desk Console to complete the task. In Raycasting, participants made an average of 4.33 control transitions per minute, while in Desk Console, 6.77 control transitions per minute. Since the data normality was confirmed, the statistical significance was assessed using the Paired Samples T-Test.

Table 5.2: Quantitative Data Results

Category		**Mean (SE)**		**Type of Test Used**	**p-value** *(*p<.05, **p<.01, ***p<.001)*
		Raycasting	**Desk Console**		
Task Completion Time (s)		665.5 (103.6)	466.8 (34.0)	Wilcoxon Signed Ranks Test	**.027***
Average time per each control (s)	Vertical Slider	6.01 (0.59)	4.83 (0.86)	Wilcoxon Signed Ranks Test	**.041***
	Rotary Knob	8.22 (3.62)	6.65 (0.86)		.507
	Horizontal Slider	3.94 (3.62)	4.36 (0.74)		.730
	Color Picker	13.73 (1.36)	8.42 (0.63)		**.001****
Control Transitions Count		4.33 (0.44)	6.77 (0.61)	Paired Samples T-Test	**.000*****
NASA Task Load Index (NASA-TLX)	Mental Demand	60.0 (6.7)	36.1 (6.4)	Paired Samples T-Test	**.001****
	Physical Demand	80.4 (5.3)	43.2 (5.8)		**.001****
	Temporal Demand	42.5 (6.3)	29.3 (5.7)		.083
	Performance	44.3 (5.8)	72.1 (3.4)		**.001****
	Effort	81.1 (3.7)	42.1 (4.1)		**.000*****
	Frustration	75.0 (5.1)	31.4 (5.0)		**.000*****
Creative Support Index (CSI)	Exploration	4.4 (0.5)	5.8 (0.2)	Wilcoxon Signed Rank Test	**.011***
	Expressiveness	4.0 (0.5)	5.4 (0.2)		**.006****
	Enjoyment	3.3 (0.5)	5.8 (0.3)		**.003****
	Immersion	4.9 (0.4)	6.1 (0.2)		**.004****
	Worth Effort	4.5 (0.4)	5.7 (0.3)		**.01***

There was a highly significant difference in the number of control transitions per minute between the two interfaces (p = .000***, two-tailed). This suggests that users were able to explore a wider range of controls within the same amount of time using Desk Console. Participants reported this aspect during the interviews as well. For example, P9 mentioned, *"Using Desk Console felt more comfortable, so I tried different controls earlier and experimented with various options, whereas in Raycasting, I focused on performing one task well rather than exploring multiple options."*

Average Time per Control

The Average Time per Control (Figure 5.4c) indicates the average time (seconds) to utilize each control once. This includes the time taken to adjust the desired value on a control, including the case if the user does not switch to another control and continues using the same one. It offers insights into the approximate performance of each control within the current user study conditions, which consist of open-ended scenarios. Figure 5.4c presents the average time (in seconds) it took for participants to utilize each control once to input the desired value. The controls are categorized based on their form factor, including vertical slider, rotary knob, horizontal slider, and color picker. Significance testing was conducted using the non-parametric Wilcoxon Signed Ranks Test. The results indicated statistically significant differences between the interfaces for the vertical slider (p=.041*), and color picker (p=.001**). The rotary knob(p=.507) and horizontal slider (p=.730), on the other hand, did not show a significant difference. To summarize, the vertical slider and color picker were adjusted significantly faster on the Desk Console compared to Raycasting, at alpha levels of 0.05 and 0.01, respectively. Further details regarding the color picker cases, which demonstrate significant differences in average operation time, will be discussed in section 5.4.3. This section 5.4.3 will examine the variations in users' actual color picker usage behavior between the two interfaces, offering a deeper understanding of these discrepancies.

5.4.2 Workload Evaluation as Immersive Authoring Tool

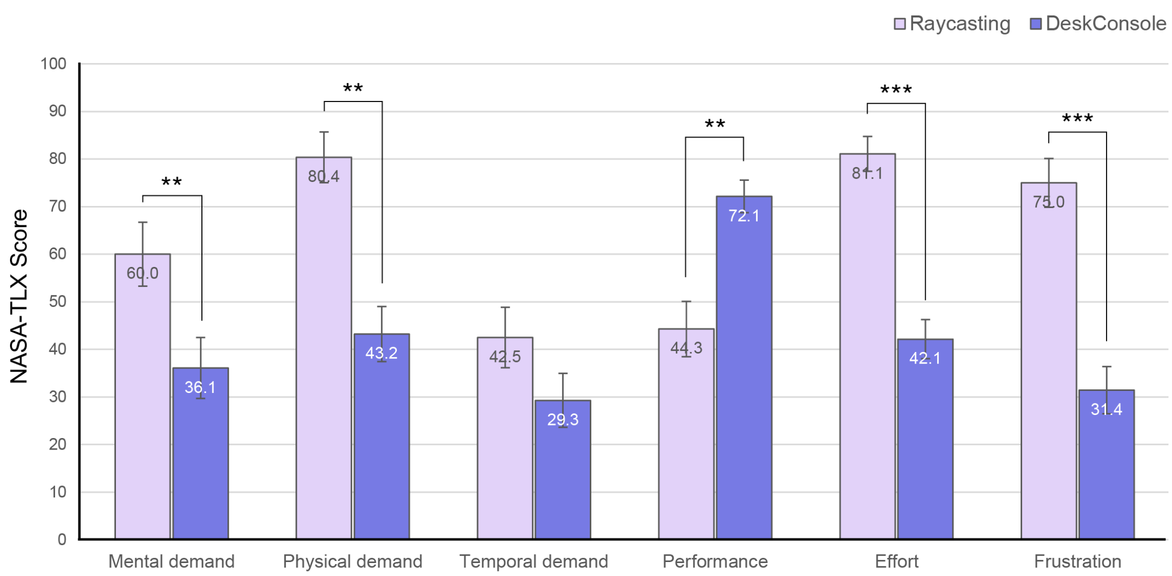


Figure 5.5: NASA-TLX score per task load factors for Raycasing and Desk Console, with asterisks indicating the level of pair-wise significance(**p<.01, ***p<.001). The error bar indicates standard error.

NASA Task Load Index (NASA TLX) [21] was employed to assess the perceived workload of each interface in this study. Scores ranging from 0 to 100 were used, with higher values indicating higher workload. Normality assumptions of data were met, allowing for a Paired Sample T-Test to determine significance. The significance level of the test was set to 0.05. The analysis revealed significant differences between the two interfaces across several subscales of NASA-TLX, namely Mental Demand, Physical Demand, Performance, Effort, and Frustration. However, no significant difference was observed in Temporal Demand.

Mental Demand

Desk Console demonstrated a statistically significant reduction in Metal Demand [t(14)=4.11**, two-tailed] compared to Raycasting at an alpha level of 0.01. Interview findings indicated that the real-world-like interaction offered by Desk Console effectively reduced cognitive load. Participants expressed that (P14) *"When working on a desk, it's almost instinctively connected to physically moving objects, so it feels comfortable to do it like I usually would. However, with raycasting, it's quite different from what I normally do, so it feels less intuitive."*

Physical Demand

Desk Console exhibited a significantly lower physical demand [t(14)=4.58**, two-tailed], indicating more comfortable work conditions. This suggests that Desk Console, supported by physical elements, provides advantages for prolonged use compared to raycasting, which relies on in-air gestures.

Performance, Effort, and Frustration

Desk Console demonstrated significantly higher Performance [t(14)=-4.23**, two-tailed] and lower Effort [t(14)=7.78***, two-tailed] at alpha levels of 0.01 and 0.001, respectively. It also showed reduced Frustration [t(14)=6.26**, two-tailed]. The aforementioned similarity of the Desk Console interface to reality contributes to a reduction in cognitive load, and the integration of passive haptic feedback through the desk leads to favorable outcomes by alleviating the operational burden. Participant 1 expressed, *"With Desk Console, it's like just pressing buttons right away, so the thought process itself feels a bit shorter. Since I immediately get feedback right in my fingure, it feels like I was able to do things right away without hesitation."*

5.4.3 Interface Impact on Creative Workflow

The Creative Support Index (CSI) [13] is a psychometric survey that assesses the effectiveness of creative support tools in facilitating users' creative work. Participants rated their responses on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). Since the Likert scale data is ordinal in nature, statistical significance was determined using the Wilcoxon Signed Rank Test, a nonparametric test. The analysis revealed statistically significant differences in all subscales of the CSI, namely Exploration, Expressiveness, Enjoyment, Immersion, and Worth Effort.

Exploration

The Desk Console enabled users to explore a significantly greater variety of ideas, options, designs, and outcomes. The score difference between the two interfaces was statistically significant at the 0.05 alpha level ($p = 0.011^*$). According to the interview, the ability to easily revert to the previous state of

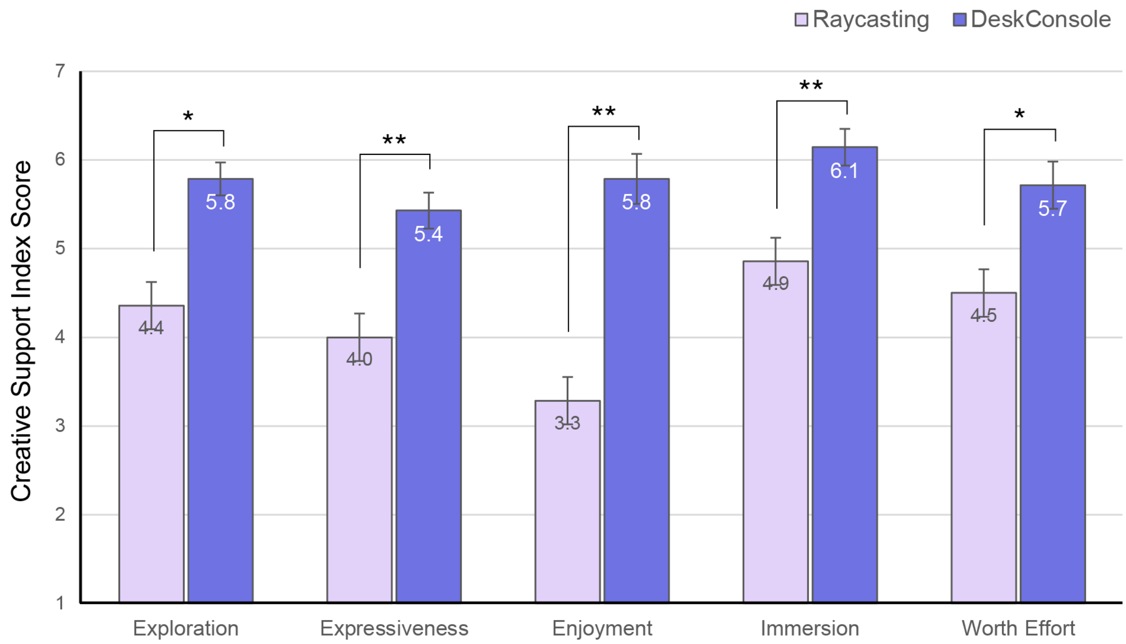


Figure 5.6: Creative Support Index score per exploration, expressiveness, enjoyment, immersion, and worth effort for Raycasing and Desk Console, with 1 (strongly disagree) and 7 (strongly agree) on a 7-point Likert scale. Asterisks indicate the level of pair-wise significance(*p<.05, **p<.01), and the error bar indicates standard error.

the Desk Console interface and its high operability encouraged users to spend more time experimenting with different approaches.

- *"At the moment when I felt that (Desk Console) was a bit more controllable, I wanted to see more of what I wanted, and I spent time because I felt like I had a more exploratory environment."* (P10)
- *"In the case of Desk Console, the control was good, so when I made changes like using a darker red color, and it worked well, I could easily find other shades of red and make decisions like, 'I should use this red color.'"* (P11)
- *"When it was just on the desk, it was easier to grab and move, so I was able to explore a much wider range of colors."* (P6)
- *"It was easier to go back to that state compared to raycasting, so I would discover something good while exploring, and then find something else good through further exploration, and I did it like that."* (P12)

Expressiveness and Worth Effort

The Desk Console outperformed Raycasting in helping users express their creative intentions with statistical significance (p = 0.006**, two-tailed). The interview findings indicated that the tactile sensation of the desk surface provided users with a sense of scale during interaction, enabling effective expression of their desired outcomes. Physical touch can enhance users' expressiveness in the authoring process by leveraging spatial awareness.

- *"When I chose colors on the surface, I could perceive my position, and it made it possible to find the desired colors more confidently. It gave me a clear understanding that I just needed to move* *slightly downward. However, when performing in mid-air, I didn't have that kind of sensation."* (P6)

- *"When I used it (on the desk), there was a sense of scale that allowed me to control more accurately and precisely because I could see the difference of double the size between this and that."* (P10)

This heightened expressiveness also correlated with the creation of more satisfying results for users. Consequently, the Worth Effort metric, which assesses the extent to which users perceive their efforts as worthwhile in achieving desired outcomes, also yielded a statistically significant high score.

- *"Maybe it's because I had a desk, so I could feel it, you know? And thanks to that, I think I was able to create it in a direction that I was more satisfied with."* (P11)
- *"Doing it on the desk, I think the accuracy was a bit higher. I could stop more in the place I wanted, and I could easily make changes to what I wanted, even if I wasn't completely satisfied. So, it made me think that I could have reached even closer to the desired outcome."* (P10)

Enjoyment and Immersion

Participants expressed a high level of enjoyment while using the Desk Console and reported a heightened sense of immersion compared to Raycasting. The differences were statistically significant at the 0.01 alpha level ($p = 0.003^{**}$ and $p = 0.004^{**}$, respectively). Notably, during the interviews, participants frequently referenced the Desk Console in terms of real-world objects, such as a mouse, keyboard (P5, P9, P14), airplane or helicopter cockpit (P13), game console pad (P3), or augmented reality (P9). This alignment with familiar objects and the tactile experience associated with them seemed to enhance the overall fun factor. Fun is a crucial aspect of immersive authoring tools as it serves as a motivator for user engagement.

- *"The button method was quite enjoyable, I must say. It had a sense of impact, if I may call it that. Just the idea of pressing a red button has a universally recognizable image associated with it. It was because of that aspect that I found it quite interesting. It provided a sense of motivation in the process of creating something fun."* (P3)

Exploring User Behavior in Color Picker Interaction

In the interviews of the Exploration metric, participants expressed notable differences in their experience with the Color Picker across the two interfaces. To gain deeper insights into this observation, the Log Data captured the pointer (or pin) movement traces on the color picker for color selection or exploration. This data was visualized in Figure 5.8. This data occurred when pinching or dragging in the case of raycasting, and when holding and moving the pin in the case of desk console. Figure 5.8 shows the movement path on the color palette image as a line. The green dot means the start point of the interaction, and the red dot indicates the endpoint. Several intriguing findings were identified by examining Figure 5.8 alongside Figure 5.7.

The color picking paths of P1, P6, P12, P13, and P14 illustrate a higher density of paths in the Desk Console interface compared to Raycasting. This suggests that users could engage in more detailed color exploration, including lighter, darker, or similar shades, when using the Desk Console. Conversely, Raycasting involved identifying more points and longer, wavering paths, which resulted from pinch-based execution and required more frequent operation control.

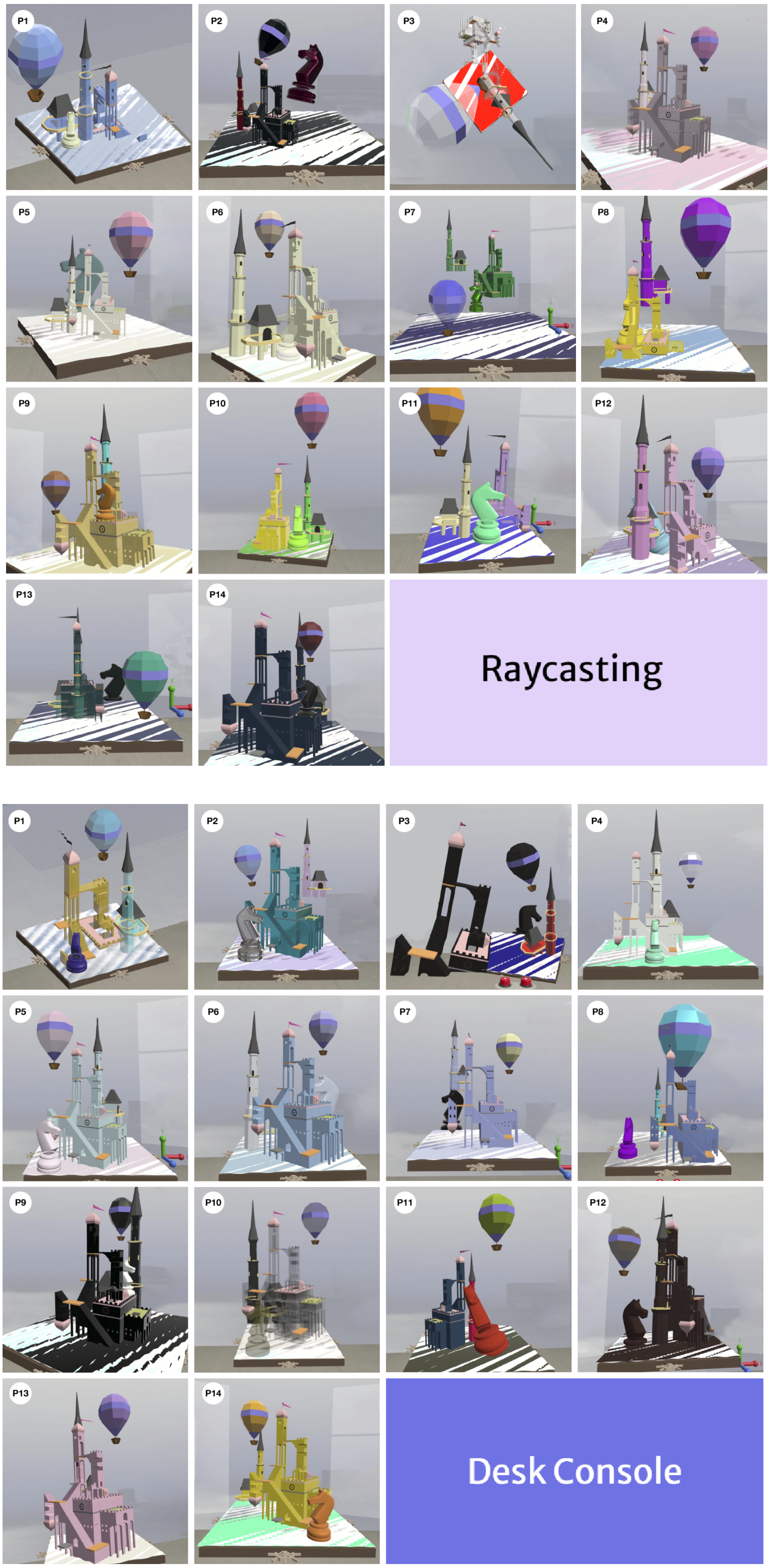


Figure 5.7: Results of content creations by 14 participants using each interface

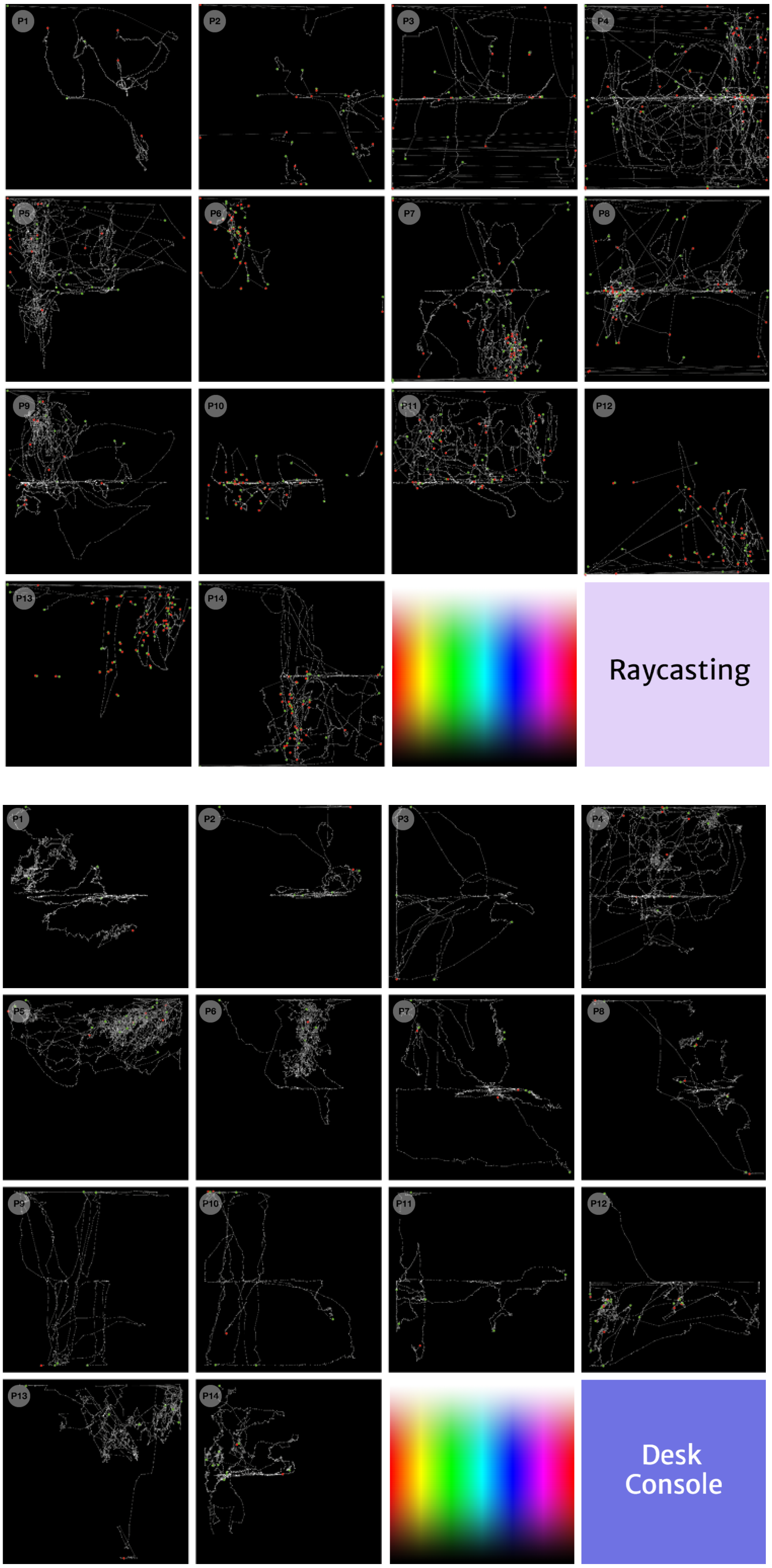


Figure 5.8: Movement traces for color exploration in the Color Picker in each interface

Furthermore, this difference in color exploration experience is also evident in the resulting creations, particularly in the works of P5, P7, P10, P11, and P13, as shown in Figure 5.7. Despite utilizing a broad spectrum of colors, users tended to employ more harmonious tones on the Desk Console. For instance, in the case of P11, Raycasting demonstrated a diverse range of color tones, including vivid, pastel, and dark shades. However, the creations using the Desk Console exhibited a sense of unity primarily in the dark tones, even when multiple colors were utilized, conveying a consistent mood and atmosphere in the creations. This suggests that the Desk Console facilitated users in expressing the desired mood more effectively.

5.4.4 Qualitative Observations

Potential for Bimanual Manipulation

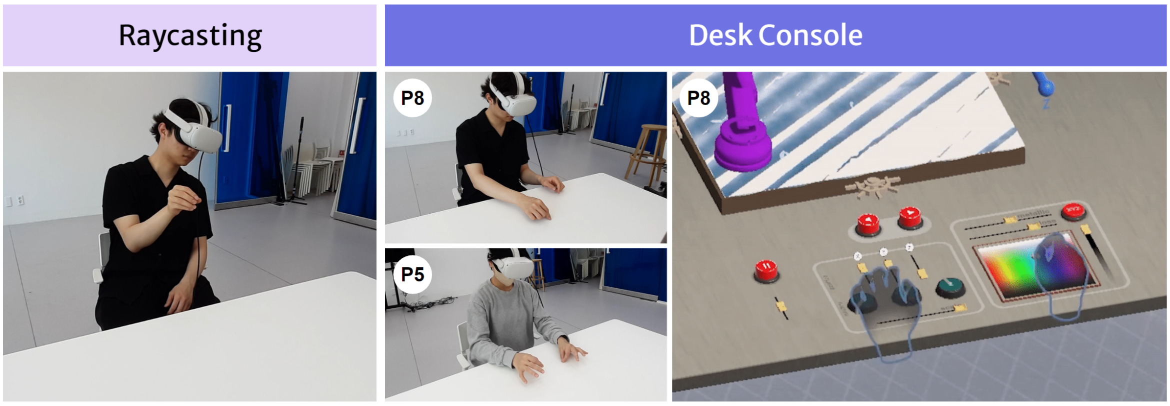


Figure 5.9: Observed two-handed manipulation on the Desk Console

Several users demonstrated the ability to engage in two-handed operations during the creative process with the Desk Console. Figure 5.9 illustrates how participants P8 and P5 utilized both their left and right hands, depending on the position of the controls. In contrast, when using Raycasting, the same participants attempted to manipulate elements on the left with their right hand, exhibiting a more constrained posture. While bimanual operation like existing physical Creative Console devices was not observed in this study, the interviews indicated the potential for such interactions and suggested their potential productivity.

- *Having something like buttons in a cognitive sense makes it much more convenient, I would say. And since I'm not yet very familiar with it, I couldn't use both hands, but I think I could. Because using both hands reduces the burden significantly.* (P11)

Gaze Dispersion Extent

During the creative work, distinct eye movement patterns were observed between Raycasting and the Desk Console interfaces. In Raycasting, participants exhibited large left and right eye movements as they shifted their gaze between the control panel and the creation itself. In contrast, participants displayed shorter vertical eye movements with the Desk Console. The interview findings support that the Desk Console enables more focused work with fewer distractions. In actual observations, most participants tended to view and manipulate their work directly after grabbing the controls on the desk console. This suggests that providing a physical reference point facilitated spatial awareness and allowed users to concentrate on their work with reduced distractions.

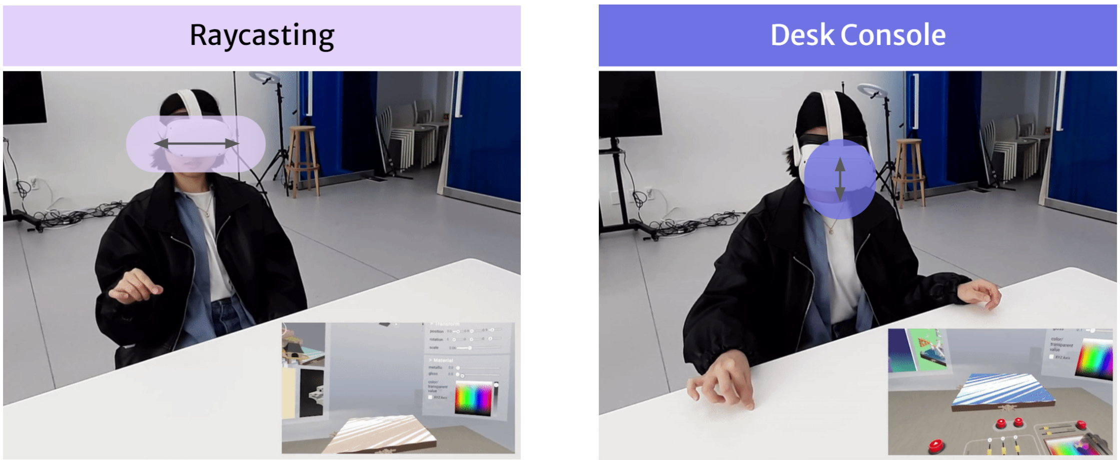


Figure 5.10: Gaze Dispersion Trends in Raycasting and Desk Console

- *"I'm not entirely sure why that happens, but with a Table Top (Desk Console), for example, when I grab and rotate it, I can manipulate it without having to constantly look at it and focus on the contents. However, with Raycasting, sometimes when I grab and move things, the pointer can inadvertently move outside the panel, causing the interaction to cancel."* (P2)
- *"I have a feeling that moving up and down made the eyes much less distracted. I feel that this (Desk Console) is firmly fixed in my hand, so I think I did it with a similar feeling, just as I didn't look at the work when I was working in Photoshop with the mouse."* (P6)

6.
DISCUSSION

Chapter 6. Discussion

In the preceding chapter, we conducted an evaluation of the Desk Console as an Immersive Authoring Interface, examining its effects on performance, workload, and creative work support. This section explores the potential extensions of the Desk Console beyond the controlled evaluation conditions, aiming to enhance its support for users' real-world tasks.

6.1 Implications of Desk Console Interface

Overall, we believe that the Desk Console interface contributes to the future way of working by introducing novel ways to interact with control panels in augmented and virtual reality. Existing immersive authoring tools with controllers offer intuitive experiences but limit the freedom of bare hands and portability. Moreover, prolonged use of such tools can be physically demanding, requiring continuous whole-body movements. On the other hand, attempts to achieve rich and natural authoring using bare hands have often resulted in compromised operability through in-air gestures. Alternatively, they have required significant development costs or steep learning curves due to the need for interface reconfiguration with specific purposes.

The Desk Console interface addresses these challenges by integrating desks, everyday objects in workspaces, as interfaces. This allows for stable and natural bare-handed operation in a comfortable posture. Based on familiar computer platform GUIs experience, the interface provides a seamless and user-friendly authoring interface, ensuring easy adoption and use. The Desk Console interface's combination of natural and stable interaction and user-friendly interfaces unlocks new possibilities for creative work in augmented and virtual reality. It enhances the immersive and enjoyable authoring experience, promoting productivity and facilitating the expression of creative visions.

6.2 Interface Scalability

6.2.1 Customization according to Workflow

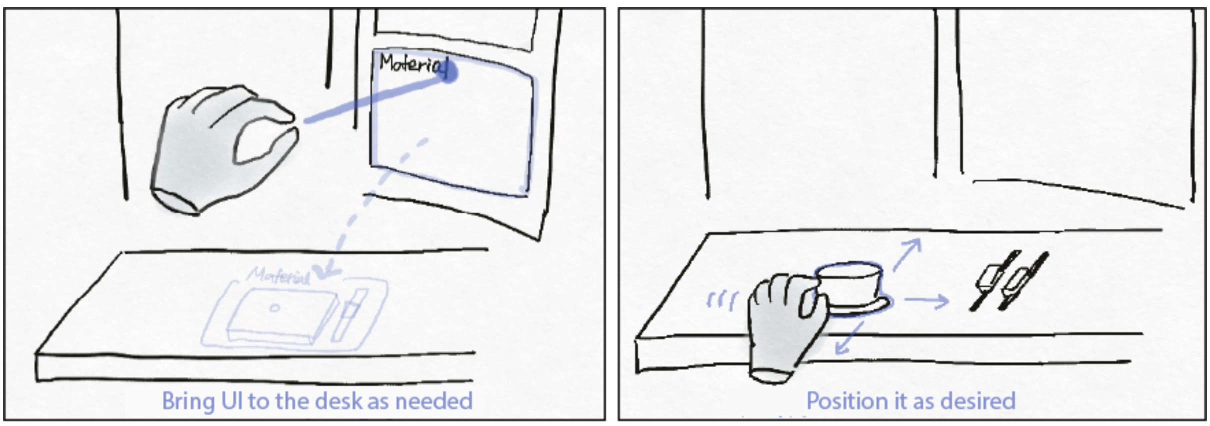


Figure 6.1: Sketch depicting the Customization of the Desk Console for Individual workflows

In the previous user study, pre-determined screen UI and mapped 3D controls were provided on the desk to compare against the baseline and task performance. However, real work processes often involve more complex control panels and require a more significant number of screen UI elements. It is inefficient to display all these elements on the desk in advance. To address this, a more flexible approach can be adopted by allowing users to detach only the necessary elements from the screen UI and place them on the desk as needed. For example, users can take UI elements A, B, and C off the screen and position them conveniently on the desk to perform Task 1. By performing a long pinch gesture towards the desired UI, a 3D representation of the UI is presented directly on the desk. Similarly, after moving on to Task 2, unnecessary elements A, B, and C can be removed from the desk, and new elements D and E can be placed. This approach empowers users to perform more flexible and customized manipulations by representing 2D GUIs in 3D to fit their workflow and requirements. During interaction design, different GUIs can be categorized based on input types, allowing for the creation of diverse Desk Console setups beyond the control panel used in this evaluation study. To support this, an automated Desk Console Generator that creates 3D objects on the desk from selected UI elements or the entire panel according to the input type can be discussed as the next step.

6.2.2 Expand to Various Surfaces of Everyday Objects

Figure 6.2: Example of Desk Console utilizing the Surface of a Workspace Object in Augmented Reality

In this paper, the Desk Console was implemented in VR to facilitate easy control of variables. However, this concept can also be extended to augmented reality (AR) interfaces, enabling the Desk Console to be performed on a wider variety of surfaces beyond just the desk. For instance, it can be affixed to a wall to work on a vertical plane, or placed on a monitor in AR and interacted with by touching it. Moreover, controls can be attached to various everyday objects used in the workspace, enabling grouping and integration by functions. This expansion highlights the enjoyment and maximizes interaction freedom of the Desk Console, while maintaining the convenience of operation through passive haptics. Further exploration of the Desk Console's placement and opportunities in AR can effectively extend the interface, considering the diverse visual elements and surfaces in AR.

6.3 Limitations and Future Work

While our findings showed that the Desk Console is useful for control panel-based immersive authoring, our work has some limitations. First, it may include long-term observations of interface usage. The user study evaluated approximately 20 minutes of usage, but actual tasks require longer durations, and extended use of the interface may impact users' utilization. Some users stated, *"If I use it for a longer period, I believe the difference in work efficiency between the Desk Console and Raycasting will increase due to the comfortable posture. (P2)"* and *"As I become more accustomed to using it, I think I will be able to use both hands. (P11)"* These insights provide valuable clues regarding long-term use but have not been validated experimentally. Users often become familiar with the interface in creative tasks and explore additional functionalities, such as shortcut keys. Therefore, conducting observations on long-term interface use can provide more concrete considerations and insights for applying the Desk Console to real-world work scenarios.

Secondly, there is room for expanding the range of demonstrated gestures. The current implementation primarily utilizes two gestures, which are easily memorizable and reliable for development purposes: pinch and poke. However, some users expressed their desire for more diverse gestures that enable more realistic interaction with objects. *"I felt somewhat constrained in expressing my ideas or what I was drawing in my head because all the diverse UI elements are controlled using the same interaction (Raycasting). On the other hand, it(Desk Console) was nice that the movements were a bit more diverse. So I think it would be nice to include more diverse gestures than now. (P1)"* In response, interfaces can be improved by exploring and incorporating more natural gesture designs without compromising the interface's learnability and operational clarity.

7.
CONCLUSION

Chapter 7. Conclusion

We present Desk Console, an immersive authoring interface that provides users with a comfortable and intuitive operation by representing the existing 2D screen-based control panel as a virtual 3D object on the desk. To consider scalability, we classify the 2D GUI elements of existing creative tools as input type, and based on the inspiration from AR/VR design principles and considerations of physical creative console devices, we represent them appropriately in a 3D format.

In order to evaluate the interface's performance and impact on the creative work, a user study was conducted using Raycasting as a baseline, which is widely used for screen interaction in VR. Fourteen participants produced creative content through each interface and provided quantitative and qualitative feedback on the process. The findings revealed that the Desk Console enabled users to utilize various functions in a shorter time and effectively reduced workload through the passive haptic feedback provided by the desk. Furthermore, the Desk Console facilitated users in exploring and expressing a greater range of designs, resulting in a pleasant and immersive work experience. These results indicate that the Desk Console successfully achieves intuitive control panel operation within a virtual environment by capturing both natural expressions of bare-handed interactions and stability, thereby further supporting users in their creative work.

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