Mindroom: General Workspace in VR

by

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ABSTRACT

With the emergence of VR, it is anticipated that we live, play, and work more so in such environments. However, thus far, few efforts have been made to consider what it means to perform general activities in VR, such as organizing files. In this thesis, I present a VR application named Mindroom. Mindroom is a general-purpose application that users can interact with to organize their files in a VR space. Through the iterative development of Mindroom, not only it gives birth to a primitive yet inspiring prototype of how people can work with files in VR, but some thoughts and issues also emerge while designing such type of applications. The iterative design method helped refine the idea of Mindroom and brought insightful input from playtest participants. This design-based research tries to answer the question about how people can seamlessly work with files in VR in the future. The thesis covers where the idea of Mindroom comes from, how the design and development process went, and what issues future designers of this type of application should consider.

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1. INTRODUCTION

Modern virtual reality (VR) has existed as a medium of human-computer interaction (HCI) for decades (Dixon, 2006). Now, with more advanced and affordable head-mounted display (HMD) devices, VR is likely to become one of the next major content consumption platforms. Indeed, most of the VR content is games, videos, and "experiences" – an activity that has fewer interactions than games but still focuses on telling stories or showing scenes (Kunst, 2019). All three types of activities are focused on content consumption: users turn on their VR to play, see, or experience something. No general-purpose application that everyone could use has ever been popular in VR. Since many believe VR to become the next major HCI platform in the future (Cipresso et al., 2018), VR should not be limited to content consumption alone. According to Statista (2017), an "intense gaming experience" only ranks at the fourth of top interesting aspects of VR among consumers. The top interesting aspect of VR is "the feeling of entering another world." It means that VR experiences should not be limited to games and interactive entertainment. VR headsets should not be another gaming console; instead, it should serve as the next major HCI platform. For example, designers could use the three-dimensional space of VR to perform 3D design. There are also examples that companies develop a VR training course to train their employees remotely. Nevertheless, these are all highly specified or professional applications. Consumers do not need or want this when they are considering buying a VR headset. For such a more general audience, one possible opportunity is to develop personal productivity applications in the VR market. Not only do they expand the capability of VR in general, but they also open a new market for VR headsets. In this project, I propose a VR application, Mindroom, that blends digital files into physical space to create an immersive, productive experience to keep their files better organized, and expand the capability of consumer VR headsets.

In modern computer systems, we have file systems, which use the interface of a file structure (i.e., users have to put files into folders, which are organized hierarchically). Such file systems are designed in the era of flat-screen computers, mouse, and

keyboard setup. They are highly disciplined and structured for computer professionals, but many average users still have a hard time keeping them in order. Moreover, the size of the flat screen limits the user's space to interact with their files. On the other hand, theoretically, in the VR world, users have infinite space. If users can put files anywhere in a virtual space in VR, they will no longer be bounded by the size of their flat screens anymore. Besides, by storing and interacting files in virtual space in VR, the user could make use of the Method of Loci (Yates, 2013). This memory technique associates memory with physical locations for better recall, and thus remember where the files are located in VR in a much better way compared to a traditional file system user interface.

In this thesis, I present a VR application named Mindroom. Mindroom is a general-purpose application that users can interact with their files in VR space. Mindroom features the ability to:

- Interact with files in a virtual space
- Customize virtual rooms to store different files
- Preview and move files freely in the virtual space

In Mindroom, users can make use of the 3D space provided by VR technology, work with their files, and keep their minds more organized. Mindroom runs on consumer-level VR headset Oculus Rift and Rift S for easy user access.

The design of Mindroom has been conducted iteratively. The idea started with clear principles and ambitious goals. However, in the process, different input from playtest participants and other people who tested different iterations Mindroom gradually shift every detail of Mindroom. For example, I built several different interfaces for some features according to feedback in the iterations, trying to find the best way. Only through the iterative design, Mindroom becomes better versions of itself for users to work more efficiently and productively.

2. BACKGROUND

2.1 Where the Idea Originates

The idea of Mindroom comes from the famous BBC TV series Sherlock. In the series, Sherlock Holmes uses the Method of Loci to store his memory in a mind palace that he explicitly fabricated in his mind. Sherlock almost remembers everything by this technique. In real life, however, ordinary people cannot maintain such a large mind palace for so long (Perrault et al., 2015). A mind palace can be digitally created and maintained by a computer system, and VR can provide immersive spatial awareness and an intuitive analogy of files into the digital space.

2.2 Method of Loci

Method of Loci, a strategy of memory enhancement that uses visualizations of familiar spatial environments in order to enhance the recall of information, is a memory technique that was first introduced thousands of years ago, dated back to ancient Greece and Roman times (Yates, 2013). Not only does the method usually work in real life (Mccabe, 2015), plenty of studies have shown that the Method of Loci works in virtual spaces, either on the desktop or in VR spaces.

For example, Legge, Madan, Ng, and Caplan (2012) built a desktop mind palace application to test if participants can better recall short term memories on a flat-screen mind palace than without this assistance. Their study showed that even with very little training, participants using the Method of Loci significantly outperform participants who are not instructed to perform a particular strategy.
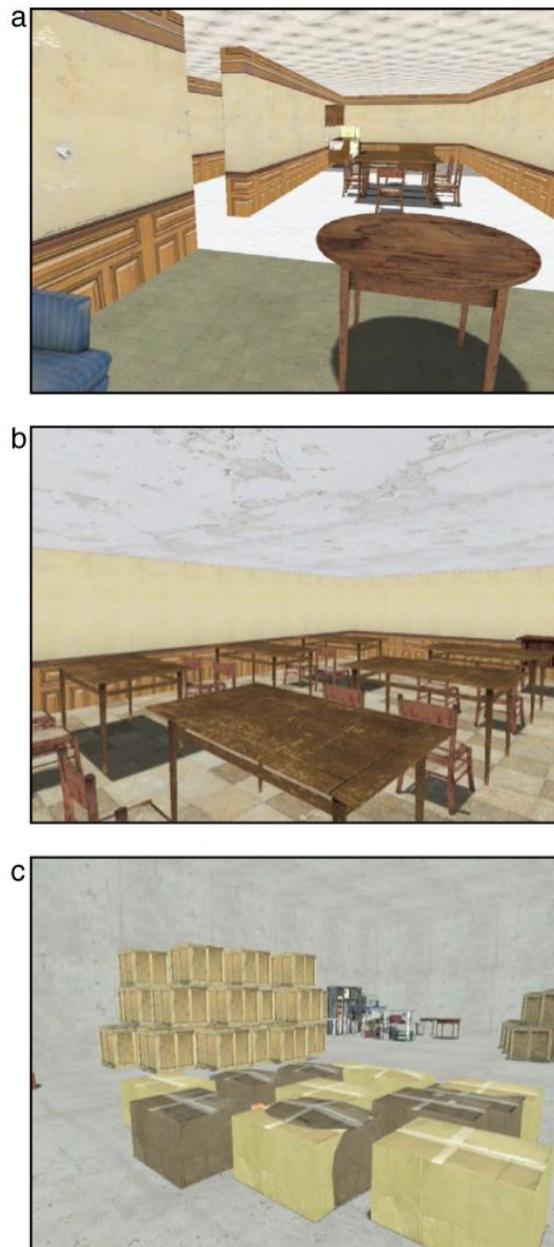
Figure 1. Three virtual environment Legge, Madan, Ng, and Caplan used

Later in 2017, Vindenes built a VR mind palace application for a similar research question and with similar results. It was built with Galaxy Gear VR, which is a reflection-based smartphone VR. Vindenes concluded that high spatial ability benefit more from the Method of Loci in VR (2017).

Figure 2. One of the rooms of Vindenes virtual mind palace project

Both virtual mind palace implementations show that participants recalled items better after they placed the items in some location of a virtual mind palace. However, both applications are created for psychological research, not for general use. In other words, they did not take advantage of the Method of Loci for building a user interface for daily use. Also, limited by the early-stage VR technology of the studies were conducted, their applications lacked graphical fidelity that today's VR technology can easily output.

2.3 Mind Mapping

Several mind mapping applications seem to work better in VR than on a flat screen, thanks to the freedom in the VR world. For example, Kuťák et al. (2019) proposed a VR mind map. Its shared virtual space allows users to be located virtually in the same meeting room and participate in an immersive experience. Users of the system can create, modify, and group notes in categories and intuitively interact with them. The multi-user collaboration is fascinating, but it does not interact with files. Then Miyasugi, Akaike, Nakayama, and Kakuda (2017) proposed a mind map manipulation system, named MMVR. This system allows multiple users to not only edit a mind map by using hand gestures, but also to share it

in virtual reality space. Some of the features of MMVR requires a more complicated VR headset with hand-tracking capability.

Both implementations are far beyond what a single-person thesis project could achieve, but the ideas are compatible with Mindroom. Mindroom combines Method of Loci, some mind mapping techniques, and a conventional VR user interface. It might not look like any of these previous implementations mentioned above, but it borrows some ideas from each one of them. In the actual development, not all ideas are implemented or investigated due to the limited time and resources.

3. APPROACH

Mindroom is a VR application in which users interact with their files (the same files that everyone is familiar with). It focuses on two main aspects/purposes: file storage and workspace. Every file will be depicted as a slate and can be held with virtual hands using controllers.

3.1 Original design vision

File storage means the users could store the files in different virtual containers, including bookshelves, drawers, desks, etc. Each container has its different physical form and capacity. Users can create, nametag, reposition, destroy the containers.

Workspace means that users could view, organize, and, ideally, edit their files. Files can be placed in the air, on the desk, or pinned on the bulletin board object. In this case, users could make use of the nearly-infinity screen size compared to flat screens, which has physical bounds. Users can build connections between files. The connections between files help users to organize their minds when dealing with tons of files. Mindroom will not have the capability for users to edit files.

Users need to assign the folder they want to work with Mindroom or import the files with Mindroom to a specific folder for each room. The structure of containers will correspond to the file hierarchy in Windows. For example, a drawer closet with three drawers corresponds to a folder with three children folders.

Users could maintain multiple rooms at the same time. At the main menu, users will start at an intersection with multiple doors closed around them. Users could create a new room by opening a door and continue customization with menus.

Mindroom was developed with Oculus Rift S, Unity, and some third-party plugins and packages.
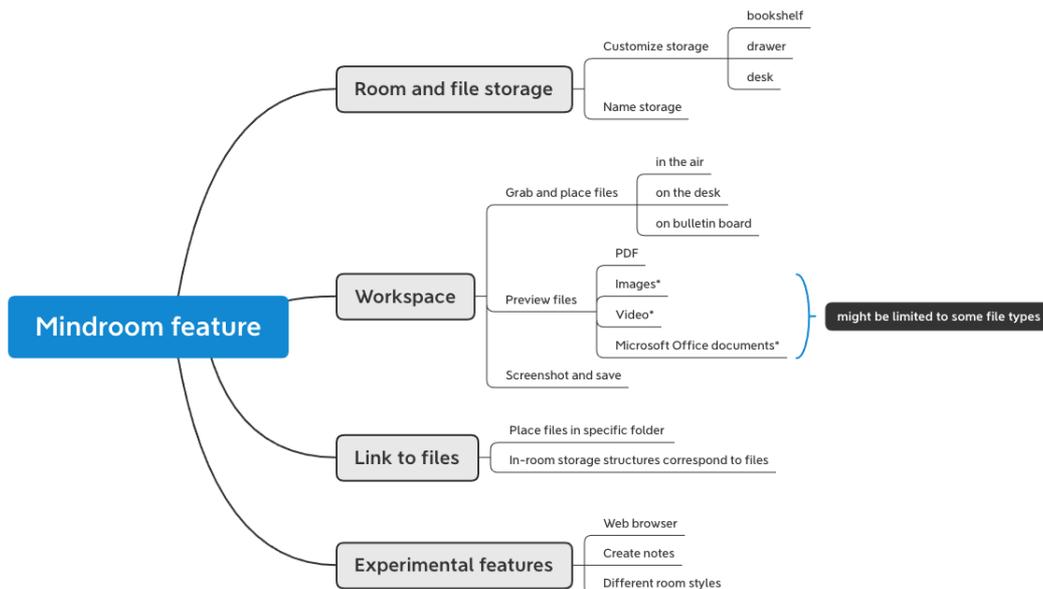
Figure 3. Mindroom feature diagram (before version 0.1)

Above is Mindroom's feature diagram of original design visions. Features are categorized into four major aspects: room and file storage, workspace, link to files, experimental features. In the final iteration of design, about half of the features are accomplished or implemented in other ways.

3.2 Development process

I apply iterative design to progressively approach to the design goal while keep correcting and compromising design choices. To collect ideas from a broader audience, I ask for comments and suggestions from people of various types around me, including family, friends, professors, employees in related industries, etc. Before the first design iteration, I ask for general ideas and comments after telling them my original idea. After the first design iteration, I ask for feedback on the existing design if they are able to experience Mindroom, or I ask for impressions after they see the video demonstration of Mindroom.

In the first iterations, I focused more on fundamental interactions, such as viewing angle, file browsing, grabbing, moving (later canceled). In later iterations, I focused more on containers, customizations, more objects to interact, and correcting existing designs.

Furthermore, for more specific and documentable results, playtests are conducted in the design iterations to get feedback from users and improve the design of Mindroom. Questionnaire surveys are distributed to gather responses after the playtests. The questionnaire consists of user experience questions, opinions about Mindroom, and general opinions about VR.

4. DESIGN ITERATIONS

In this project, I implemented an iterative design where I rapidly gathered feedback from users and reiterated my design. I divided the whole process into 4 phases. At the end of phase 2 and 3, I performed playtests to gather feedback from participants. In other phases, I typically formed ideas by myself and asked peers for comments. All details within each phase will be elaborated in the sections below.

4.1 Phase 1: Idea consolidation and technical verification

I started designing Mindroom after the idea emerged. The features I designed for Mindroom are shown in Figure 1 above. In the beginning, the focus was to neatly organize files in a VR environment. After I talked with others about Mindroom, I realized that Mindroom also has the potential for users to interact with files.

Per suggestions, the space in Mindroom should not be limited to a room that resembles the physical rooms in our real lives. Instead, it can be more fictional. For example, users could make their "rooms" in a Medieval castle, in the woods or even on the moon. It creates an alternative reality for users so that they have a distinct memory of objects in real life or in Mindroom. This feature requires more assets in the final project and might be subject to change depending on the actual development progress.
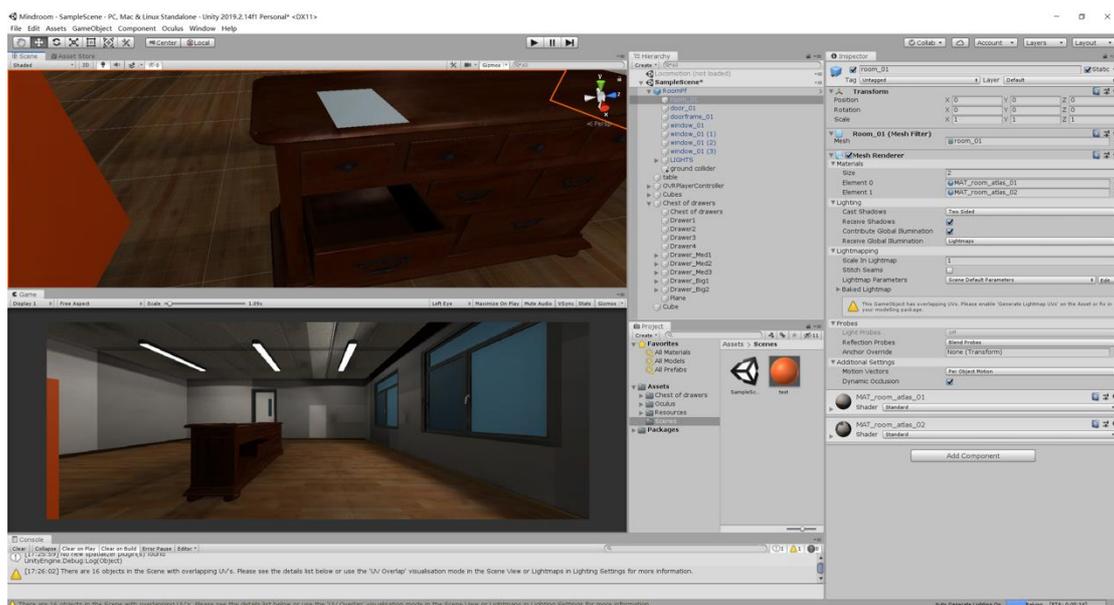

Figure 4. A screenshot of the technical verification project

Also, in this phase, I consolidated some principles for Mindroom's design:

1. *Efficiency first.* For work applications, efficiency should always be on top of all requirements. The existence of the application should accelerate workflow rather than put more burdens on the users.

2. *Minimize body moves.* Because it could serve as a workspace application, users are not supposed to have ample space to stand, walk, stretch, swing, etc. The whole experience should be completed within the area of a typical office seat and desk area.

3. *Minimize the learning process.* For general users, especially in the workspace use case, users might not have any VR experience, while they have to learn and work with it to complete their workflow. Therefore, Mindroom should not require users to know high-level VR tricks or even expect users to have preliminary knowledge of VR.

4. *Link between Mindroom and desktop workflow.* Mindroom serves as a supplement to today's desktop workflow. It helps to organize files and ideas, but it is not capable of replacing any major workflow in the foreseeable future. Therefore, the users should take no effort switching between Mindroom and their existing workflow.

The principles above guided me to confirm basic interactions to serve as fundamental elements in Mindroom. Interactions like grabbing, avatar moving, posture, and controller behaviors are the foundation of a VR experience. In Table 1, it shows Mindroom's choices and the reasons behind them. These choices are made after thorough testing and discussion. For example, whether or not the user can move in Mindroom is one of the biggest concerns at the beginning of the design. If the user can move, it can tremendously expand usable space of a single room, but the user also has to deal with exponentially increased spatial arrangement issues. Given that Mindroom is planned to have the capability to maintain multiple rooms, I decide not to allow the user to move in the space. Instead, they can focus more on space around them.

Interaction	Mindroom's choice	Reason or concern
Grab	Distance grab	Minimize arm stretch and body move
Avatar move	No avatar moving	Prevent vertigo (pan moving) Minimize learning and space (teleportation) Large VR space is not easy to manage
Posture	Sit	Minimize cost to switch between Mindroom and computer work More relaxing than standing (same as computers)
Controller	Single controller only	Minimize cost to switch between Mindroom and computer work Minimize learning

Table 1: Basic interactions in Mindroom and why

The choices might not be correct, and if possible, Mindroom should provide all kinds of interactions for better compatibility. In this project, I only chose one of each for the ideal use case of my expectation, as listed and explained in Table 1. Later during playtests, it proved that users are satisfied with these choices. These results will be shown in later sections. Finally, in this phase, I started to learn development on Oculus Rift S with Unity3D, to see if this combination is capable of my development goals.

4.2 Phase 2: Build basic functionalities (Mindroom 0.1)

After the idea consolidation and technical verification, I started to develop a working build of Mindroom. I call this version 0.1 because it only has fundamental interactions, but it is also the first working build.
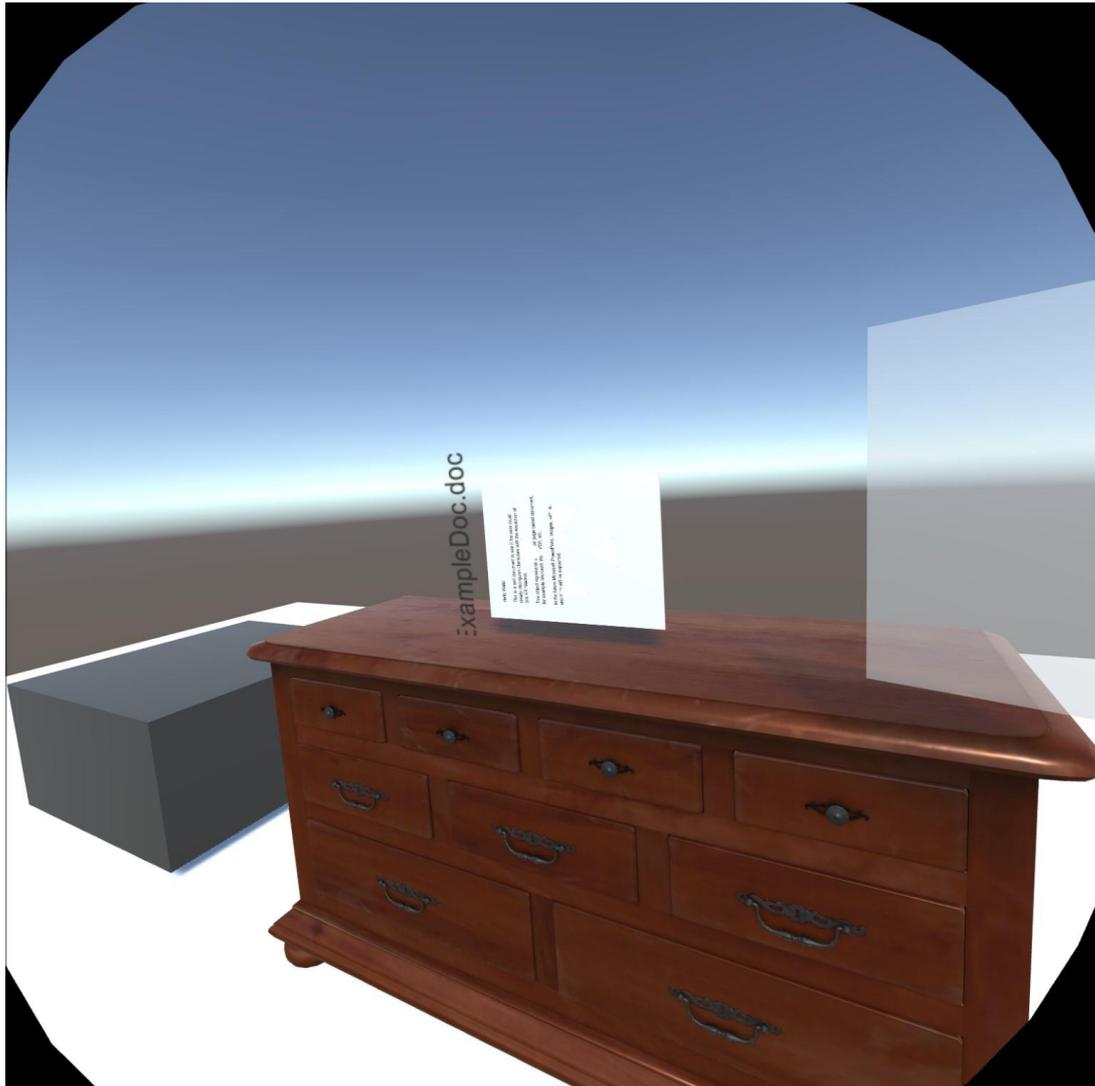
Figure 5. A screenshot of Mindroom 0.1

As shown in Figure 3 above, an example file is placed above the chest of drawers. On the right is the anchor area indicator, where the user could pin a file in the air like a pinboard. The user uses their right controller to distance grab files by pointing at the file and push the hand trigger button. Then the file would fly into the users' grab. The user can also open a drawer by pointing at the drawer and pushing the B button. More details about the designs and why are elaborated in Table 2 below.

Item	Feature	Description
Sample file	Distance grab	A text file that looks like a white slate. The user could perform a simple grab gesture towards a file from any distance in the environment, and the file would be absorbed into the grip.
Chest of drawers	Push button to open or close targeted drawer	Drawer mechanism links deep into the VR SDK that I cannot make good enough drawer interactions by only using the default grabbing hand. Button interaction is a compromise.
Anchor area for file float	Make files float in the air for a better reading experience	In version 0.1, files follow physics rules and receive gravity. In other words, they fall into the ground if users release their hands. But it is impossible to view multiple files at the same time if users have to grab and hold files in their hands. Therefore I designed an anchor area in the air where users could anchor their files so that they can keep multiple files at correct positions for a better reading experience.

Table 2: Feature list of Mindroom 0.1

These features were the first design attempts of the fundamental interactions of Mindroom. They were mostly primitive and designed based on my prior VR experience. This 0.1 version soon underwent the first playtest of 12 participants, 9 of which gave written feedback on the open response options on my survey. During the playtest, the participants were guided to perform the basic interactions after an explanation of the project. Here are some key insights from the survey responses and direct conversations:

1. For the question "How much do you like the idea?" the mean was 6.0 out of 7 ($SD = 1.12$). However, in the following question, "How likely do you want to use this kind of user interface in your daily workflow?", the mean was only 4.78 out of 7 ($SD = 1.20$).

The gap reflects that this v0.1 build did not effectively deliver the ideal experience that meets users' expectations.

2. For the question "Will you feel more organized if a well-polished Mindroom is available for you?" out of nine total participants, four participants responded with "Yes", and five responded "Maybe". It seems Mindroom could serve the purpose well if well-polished, and I was in the right direction.

3. Per the suggestion of one of the participants, in Mindroom the containers could be abstract or imaginary objects that do not exist in real life, such as magic bubbles; or the object only serves as visual and locational purposes, such as an animal as a container.

4. Another suggestion, the drawer can open automatically when a file or hand approaches the drawer.

5. Most participants tried to grab and pull the drawers even if I told them to push the button to open. This implies that in the VR environment, users might be inclined to use natural interactions for the objects they are familiar with.

6. All participants have at least a little bit of VR experience, so they should have no problem understanding VR.

From the insights above, I planned to make changes for the next version: Mindroom 0.2.

4.3 Phase 3: Improve basic functionalities and add more features (Mindroom 0.2)

After the first playtest, I started another phase of design iteration. This 0.2 version combines some of the suggestions from the first playtest and other planned features. Table 3 below is the change list of version 0.2. Details will be elaborated in the next paragraph.

Item	Change or new feature	Description
Sample File	No longer receive gravity, float in the air on release instead	Now when the user releases the grip that holds a file, the file would stick to the posture on release instead of receiving gravity and fall.

Chest of Drawers	Changed button-to-open to approach-to-open	Now when a file or a hand approaches a drawer, a drawer would open automatically, and vice versa.
Anchor area	Removed	Mentioned in Sample File description.
Desk with drawers	Added another kind of container "desk with drawers."	This new container consists of an L-shaped desk and three drawers. Items can also be placed underneath the desk.
Menu on hand	Added a menu on the hand	The user can pull up this dial-shaped menu by pressing the B button. Details will be explained separately below.
Trashcan	Place a file in the trashcan to delete the file	By default, this trashcan is placed under the default desk.
Build mode	Added functionality to place more containers in the room	The user can place a new chest of drawers on the ground by pointing at the ground and rotate by tilting thumbstick.

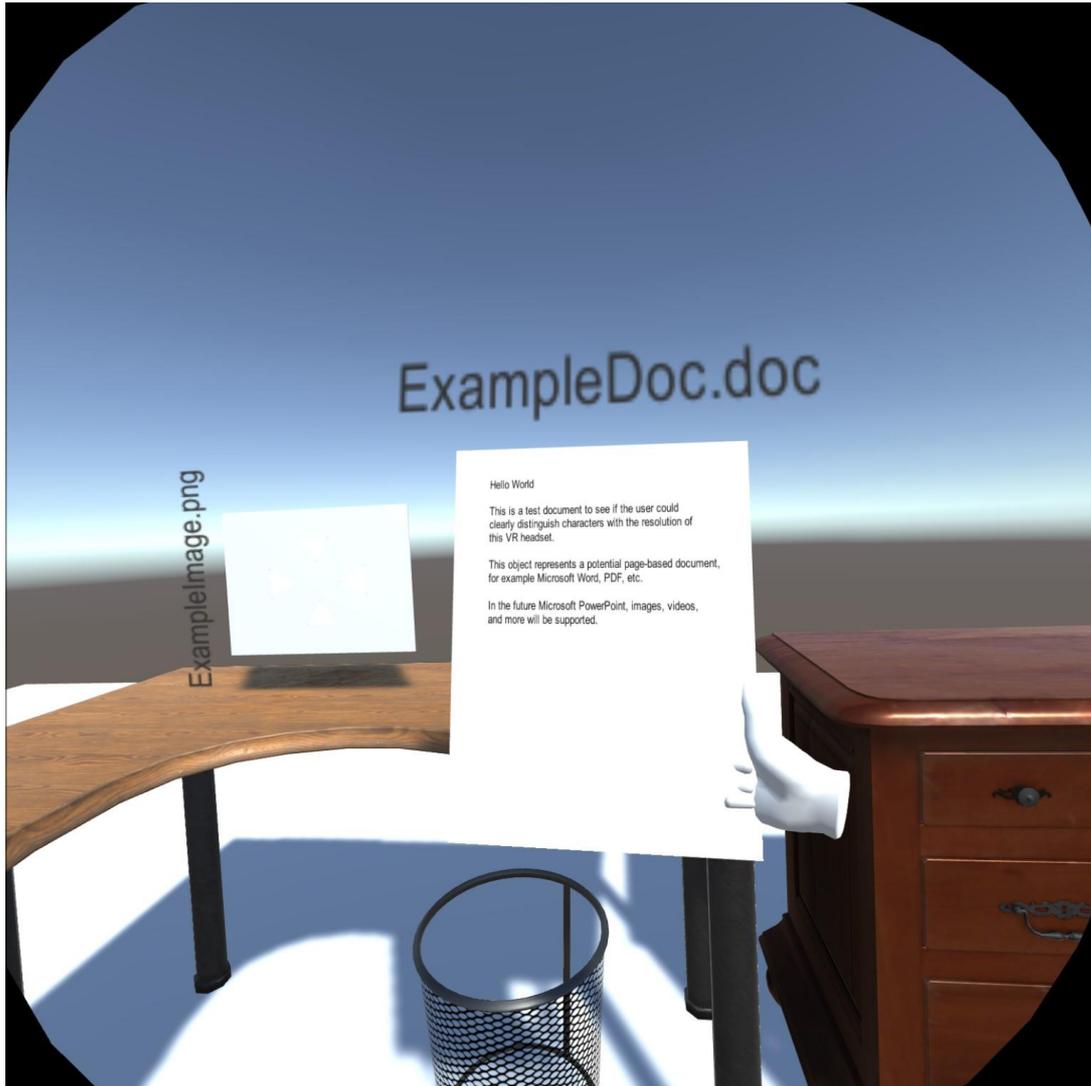*Table 3: Change list of Mindroom 0.2*

Figure 6. Screenshot of holding an example file in Mindroom 0.2

Figure 4 depicts a typical use case of Mindroom that the user is holding a document to read. In version 0.2, the user can release the grab, and the file would float statically at release. Thus, the user does not have to hold it to maintain the viewing angle. Also, it shows the trash can where the user can put the file that they do not want in this room anymore to delete it.

The build mode is the biggest new feature in version 0.2. To enter build mode, the user needs to push the B button on the controller to summon the menu. The menu consists of three objects: marker (tag mode), hammer (build mode), and magnifying glass (search mode). The user navigates through objects by tilting the thumbstick on the controller and pull the trigger to select. I chose the objects to represent different modes because they are the common objects that serve as icons in traditional 2D UI design. As shown in Figure 5 below, the

hammer represents build mode, marker represents mark mode, and magnifying glass represents search mode. The user tilts the right thumbstick to navigate through objects. A white cube will serve as a cursor to help the navigation. Once the user enters a mode, the object will be automatically held in hand, and the hand will behave differently than the default mode. Note that only the build mode was fully developed and implemented in version 0.2.
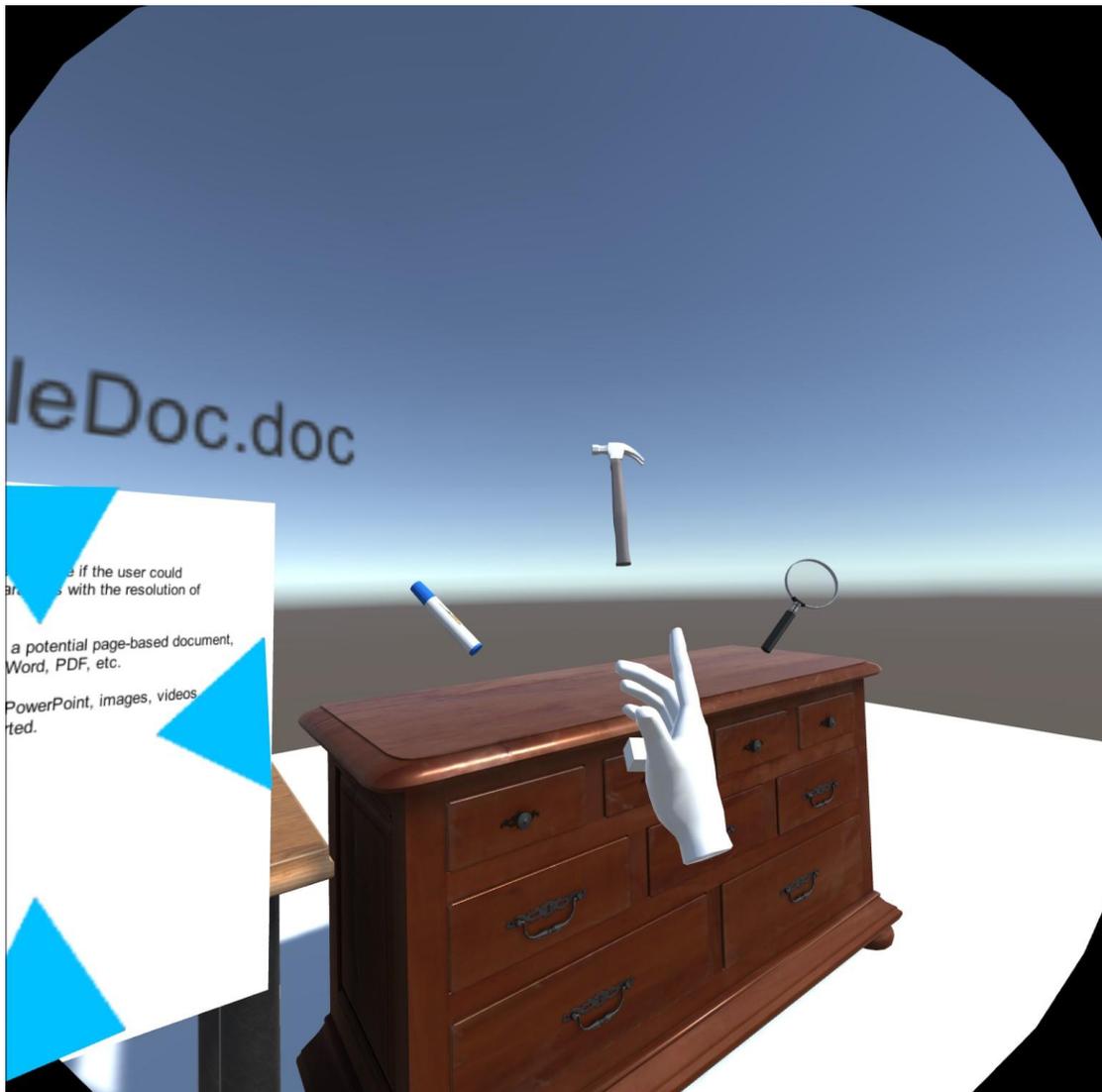

Figure 7. Screenshot of the hand menu in Mindroom 0.2

At the end of this phase, I conducted another playtest on this version 0.2. Six participants attended this playtest, and all of them responded to a survey. The survey was divided into two groups: group A consists of three participants who also participated in the first playtest, and

group B consists of three who did not. The questions for the two groups are slightly different. The questions for group A mainly focus on the new features and changes made in version 0.2 compared to 0.1, while questions for group B are the same questions in the questionnaire in the first playtest. In the playtest, the participants were guided to perform some interactions after explanation of the project, or what is new in version 0.2 if they participated in the playtest of version 0.1. Here are some key insights from the survey responses and direct conversations:

1. Participants expressed that they were more satisfied with the approach-to-open drawers compared to push-to-open. However, all 3 of them who made responses in their part of the survey that they still preferred pull-to-open. The other 3 participants did not have the same question in their survey, but they also expressed similar ideas.

2. Participants were very satisfied with the trashcan to delete function. (Mean = 6.33 out of 7, $SD = 0.58$)

3. Most participants misunderstood the functions of the menu items. For example, they thought the marker is to draw, and the hammer is to destroy items, the magnifying glass is to magnify items, etc. Although I used the items that are very common to represent the same functionalities in 2D UI design, obviously in VR, they show different affordances to users.

4. Most participants (2 out of 3) prefer to use life-like interactions to achieve functionalities.

From the responses and observations, I found that users' expectations of Mindroom diverged more from my assumptions than I expected. I tinkered the functions to the best I can do, but sadly, users wanted something else. The nature of a thesis project, as well as under an exceptional circumstance of COVID-19 pandemic, limited the opportunities to playtest and build more iterations. However, since the project is to provide insights to further implementations of the idea of file organization in VR, Mindroom has served its purpose.

In the next iteration, version 0.3, I will make some final changes to make Mindroom more complete. Also, I will answer some of the requests from the second playtest.

4.4 Phase 4: Polish and expansion (Mindroom 0.3)

After phase 3, the design focused on polishing and expanding current functionalities.

In previous playtests, participants expected more ways to interact with the objects in

Mindroom, even though I chose to avoid some of them. Also, there will be features to make

Mindroom experience more complete. Below is the change list of version 0.3.

Item	Change or new feature	Description
Sample File	Add Sample Image File	To show how image files look in Mindroom.
Chest of Drawers	Add pull-to-open	Now users can switch between approach-to-open and pull-to-open drawers.
Menu on hand	Change icon objects Add text labels of different modes	Since the old icon objects caused ambiguity, the marker will be replaced with a tag. The hammer will be replaced with a blueprint. The magnifying glass will be replaced with a contact lens. These objects are subject to change because of their affordance implication or based on the result of playtest.
Tools on the desk	Make objects to switch modes available on the desk	They can be summoned by hand menu or picked up on the desk.

Table 4: Change list of Mindroom 0.3

There are more requested features like tag mode, virtual style objects, diverse environment,

etc. However, in this project, I am not able to build them all. While Mindroom 0.3 will be the

final version for this thesis project, but Mindroom is capable of much more.

5. DISCUSSION

Throughout the whole process of Mindroom design and development, I found there are some internal dilemmas that I always tried to balance. Some of these design dilemmas might appear in other design problems, but in this VR workspace design, they had more impact on design decisions. Most of the dilemmas come from the conflict between my initial assumptions elaborated in section 4.1 and the feedback from the playtests and other communications with users.

5.1 Interactivity vs. Productivity

For productivity applications on the desktop platform, users usually want ultimate efficiency and put design interactivity into second place. However, in a VR environment, where users have far more capability and freedom to interact with the application, users turn to request more interactivity.

For example, in Mindroom 0.2, users can switch the menu by pushing a single button to pull out the menu from their hand. They can do it wherever and whenever they want. However, instead of a pop-up menu, they requested the objects representing different modes to be items to pick up from the scene. Users top the convenience and efficiency of an always-ready menu by interactivity or playfulness of "real" objects. I interpret this preference as that the intuitiveness of "real" objects beats the convenience of the hand menu in a single test. This dilemma needs more and longer playtests from different similar applications to investigate.

5.2 2D design vs. VR design

In Mindroom, I deprived some design patterns or conventions of traditional 2D UI design. For example, in 2D design, the "build" function typically uses a hammer as an icon or button, the "search" function typically uses magnifying glass as an icon or button, etc. But these conventions seem no longer make sense in VR. In Mindroom 0.2 playtest, no user perceives hammer as "build"; instead, hammer is perceived as destruction. A similar misunderstanding happened to the magnifying glass. Some users tried to see through the glass to magnify objects.

This confusion might because, in VR, objects are mostly in very high fidelity and projected in scale. Users perceive the objects have affordances identical to their real-life origins. In 2D design, designers started by metaphorizing objects like the hammer and magnifying glass to reflect the functionalities. After years it becomes the norm, and every user understands what they typically mean. However, in VR, it might no longer be the case. According to *The VR Book: Human-Centered Design for Virtual Reality* (Jerald, 2015), the hammer or magnifying glass here seem to be designed in 3D tool pattern, which should enable users to directly manipulate an intermediary 3D tool with their hands that in turn directly manipulates some objects in the world. However, they cannot afford to manipulate objects based on users' common sense. Therefore, it can be assumed that in the VR world, users can easily interpret that 3D tools have the same affordances as their origins in real life. Further research or playtests should help to investigate.

5.3 Real vs. Virtual objects

Although not implemented in any of the Mindroom versions, virtual object, which means some object that does not exist in real life to serve as containers or other functionality, is one of the most expected features. These unconventional objects, like spherical bubbles floating in the air or spell circles, can provide much more distinct spatial or visual clues to remember the locations of files. I agree with the idea of virtual objects, but I have two major concerns about virtual objects. First, virtual objects usually do not provide the same container affordances as real-life objects like drawers do. When users see a drawer in the scene, they can understand the drawers are capable of storing things. Second, virtual objects might ruin the visual consistency of a realistic style environment. Although the environment is also not implemented in any of the Mindroom versions in this project, I assume the room should be in a realistic style by default to minimize the learning process. Nevertheless, I agree that virtual objects, if implemented, could be only available to experienced users, to cause less confusion to new users but benefit veterans. If possible, further research should be able to test the performance of virtual objects and compare them with real objects in VR.

6. LIMITATIONS & FUTURE WORK

Mindroom is a general idea about a VR workspace. This thesis project only achieved a tiny scratch of a potential final, consumer-level product. A great number of further design attempts, investigations, research can enroot from this project. Some of the limitations below are also suggestions for further research or design.

6.1 Research on Method of Loci

In this project, there was no research regarding how Mindroom improved users' memories of the locations of their files. If time allows, a research could be conducted to investigate the performance of Method of Loci in Mindroom.

6.2 Mind mapping functionalities

The mind mapping functionalities like Kuťák et al. did in their project (2019) was not implemented. Such functionalities require a huge amount of work and testing that exceeded my time and resources.

6.3 File system integration

The biggest function-wise shortage of Mindroom is that it does not link the in-app objects with a real file system. All files and containers are demonstrative and not physically related to the file system. It only attempted to investigate different kinds of interactions and user interfaces. If given more time or resources, the file system integration should be at the top priority to test if this kind of application is practically useful.

6.4 Multi-room support

Mindroom should be capable of maintaining multiple rooms for different purposes. Users can create different rooms with different containers and distinct environments and work with different files.

6.5 Environment design

In this project, Mindroom has an environment with minimal visual design. The environment should play a huge role in Mindroom's experience, but there was no time to implement one. Different environments should provide additional visual cues for users to locate their files or provide more distinction between different rooms. It could cost a huge amount of work designing different environments, but Mindroom should have such capabilities.

6.6 Functionalities about files

In Mindroom, users should be able to do more things with files other than viewing and storage. For example, users should be able to mark, tag, connect, search, filter files for better navigation or organization.

6.7 Other approaches of user interface

In this project, Mindroom only implemented a single set of user interfaces. Each interaction can be potentially replaced or supplemented by other approaches. Users should be able to switch between them and get the best efficiency.

7. CONCLUSION

Mindroom is an experimental project that attempts to build a VR workspace for general use. Everyone could find it useful if it is well implemented. This project only touched a tiny portion of what applications like Mindroom can ultimately achieve. In the process, I summarized some basic assumptions to design a VR application, iteratively designed a viable version of Mindroom, gathered feedback from users by playtesting, and integrated the insights from the responses into next design iterations. Because of the constant assimilation of ideas of different sources and my personal experience, the idea of Mindroom also shifts profoundly from the origin of the project. From a spatial-based file organization tool in VR, Mindroom's idea shifted to, at least, a fundamental structure of a general workspace that could serve various purposes if supported with more development. This project could inspire other designers and developers, focusing on productivity in VR and could serve as a basis or example of such applications.

In the design process, I also find some essential conflicts in designing VR applications: interactivity vs. productivity, 2D design vs. VR design, virtual objects vs. real objects. These design dilemmas are either general to VR application design or limited to Mindroom design only. However, most literature about VR design mainly focuses on VR games or other content consumption design patterns. Not too many address VR application design patterns. As VR technology and market develops, more studies into this area should be considered.

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Mindroom is a single person graduate thesis project that I pushed myself to the limit. As a first-time VR developer, Mindroom is a broad and bold idea to start with. Thanks to the help and support from my family, Professor Casper Harteveld, my friends, and all others who listened and commented, I made it through and built something substantial.

Also, due to the catastrophic COVID-19 pandemic, research and playtests must be forfeited for safety reasons. Again, Mindroom is a broad idea that can extend to an operating system-level project. The practical focus of the actual development shifted a bit to a usable prototype to demonstrate what Mindroom could look like. As such, this project serves more like the Chinese saying to "throw a brick to attract jade." I will be thrilled if anyone gets inspiration from Mindroom to produce something similar to facilitate productivity in and through VR.

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