SPATIAL INTERACTION IN AUGMENTED REALITY AS A WAY TO EMBED DYNAMIC INFORMATION IN ARCHITECTURE SPACES

by

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ABSTRACT

SEYEDALIREZA FATEMI. Spatial interaction in Augmented Reality as a way to merge architecture and information. (Under the direction of Professor ERIC SAUDA)

Nowadays huge amounts of information are transferred to people in architecture spaces. This information is generally presented either through different types of physical signage and environmental graphics or digitally through mobile or computer apps. However, existing methods are not sufficient to effectively communicate information in many different settings. Physical information is often not enough to dynamically communicate the vast amount of available information, while digital solutions such as mobile applications can disengage people from environments. In this thesis, I aim to address this real world problem by developing design solutions that afford communication of large amounts of information, while taking advantage of users movement through spaces.. To this aim, I develop Augmented Reality applications for museums that take advantage of users movement through spatial and proximity based interactions and dynamically communicate large amounts of information about objects. Specifically, the interface uses distance, orientation, and head angle of users towards objects as inputs for interaction. To evaluate the system, I conduct two consecutive user studies. First, a usability study that aims to understand the intuitiveness and discoverability of our proposed system as well as the proposed spatial interactions and second, a domain expert study to understand how receptive museum curators are to the idea of using such applications in

real world settings. I find in general users easily interact with proximity and orientation based interaction, while they have issues in utilizing the head angle interaction technique. I also find that domain experts are very receptive of this system while they think a combination of spatial and direct interaction in the context of mobile Augmented Reality would be the ideal solution.

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CHAPTER 1: INTRODUCTION

In an Architectural environment, information is generally presented either through different types of signage and environmental graphics or through mobile or computer apps. Routinely, we use different types of Signage and wayfinding to organize information and present it to users. However, existing methods are not sufficient to effectively communicate information in many different settings. Signage sometimes is not enough to communicate the vast amount of available information, while mobile apps such as google maps can disengage people from environments. it seems that architecture and information are two completely separate and distinct objects. However, users always experience space and information in a space at the same time. The information is not considered in the design process and is not embedded in the architecture spaces.

This problem can become harmful in spaces where the information transfer is crucial to the experience of users. For instance, at a university, students have lots of challenges to find their classes specifically in indoor spaces where they do not have access to the GPS. Another example can be the shopping malls with a large number of small retail stores, where, if a customer looks for a specific item and tries to find it on the map, it could be very time-consuming. Beyond wayfinding, there are a number of spatial typologies where large amounts of information about different objects or spaces need to be communicated to the user. For example, in a museum, there might be many pages of information about specific artifacts, however, curators are typically limited to very small panels with texts. These kinds of spatial typologies that users can find different information about various objects based on their location in a space constitutes my problem.

Generally, the issue with existing physical information systems are:

1- Limitations in physical space of signage to provide adequate information

2- The need for personalized information in signs

3- High costs for changes in physical information systems. Information cannot regulate itself based on location of user.

4- High and unscalable production costs

Augmented Reality (AR) technology is one of the most novel spatial inventions in recent decades. By augmenting a display of real-world environment and spaces with virtual objects and information, AR can transform physical spaces into innovative user interfaces and influence multiple industries including architecture [1]. AR's popularity is expected to grow with the market to reach $117.4 billion by 2022 at a compound annual growth rate of 75.72% (Forbes Agency Council, 2017).

Through AR, Architectural designers can embed virtual information into physical spaces as well as fuse virtual and physical objects together. AR has already made considerable impacts on different parts of architectural process. However, AR is rarely thought of as an element to be designed, and currently it is mostly thought of as an extension to existing spaces [2]. The dynamic and interactive nature of AR has the potential to solve many of the mentioned issues with communicating information through spaces. The following are some categories of ways that AR can help us solve these issues:

1- Presenting Dynamic Information:

Unlike physical objects that are static, virtual elements can move, rotate, and scale themselves based on different factors that we can use to define them. For instance, we can have a hierarchy of data that can be presented based on size. For instance, at the first stage the user can see the type of information and when he gets closer to the object he can see

more details about it. To clarify this example, imagine that a user is in a museum and sees different artifacts. In more detail, the way that data is presented is that when he/she looks at the different artifacts, only the information about objects that are right in front of him/her will be visible, and this is going to happen based on head movement and orientation.

2- Presenting Personalized Information:

Different users have different goals. So, they are going to receive information they need. In this system, users have the ability to select specific data they desire to gain and filter it through their needs. As an example, airports are the spaces that different passengers have different destinations. So, they do not necessarily need to know about all flights. The data can regulate itself with the destination of the users and flight timings, and it can also suggest convenient stores like coffee shops or restaurants on the way to departure gates.

3- Updating Information:

It is very important for us to be able to add, remove and update the information. For instance, in universities, each class or amphitheater has different subject at a different time, and it is very cumbersome for this information to be updated physically. However, if we connect their presentation system to the database now we can automatically update this information. For instance, in museums, each object can be connected to their historic stories so that over time we can add more to them, or even connect the stories to other related objects. Updating physical information is very hard, but with the help of this system we can connect it to databases and update them in a very fast way.

4- Direct Interaction with AR Objects:

This is one of the greatest strengths of augmented reality for physical objects. Users have the ability to manipulate and explore more. For instance, in museums, if users want

to know more about a set of objects and know the relationship between them, they can easily do it through the augmented reality. It seems so difficult to filter through physical information and find out those relationships. There are many different ways of direct interaction. Typically, this is through hand motion and gesture interaction. Another way is voice interaction, where users can talk to the system and ask for information. Furthermore, a direct interaction can be done by interacting directly with a physical object. Users can use an object with clear affordances to talk to virtual objects.

5- Interacting Spatially with AR objects:

One of the things that is typically impossible with physical objects is the ability to reconfigure the information based on their location, rotation, and proximity of the user. The system can understand the user's exact location in the space and provide the appropriate information to him. The provided example for dynamic information in museums is based on spatial relationship.

Most of the existing literature on AR and architecture focuses on it as a tool to enhance existing design processes. To the best of the author's knowledge, little research has explored AR as an interactive architectural element and its effects on user experiences and subsequent behaviors. Thinking about AR as an Architectural interactive element that can be designed opens new import research questions for designers. Namely, what is a proper design process for architects and what are the appropriate interaction techniques for AR within spaces.

Designing AR within the architectural design process also brings many challenges as it adds complexities of interaction design and requires architects to understand what are the most intuitive and useful interaction types for presenting information. As movement

and exploration is an integral part of the users' experience in architectural spaces, capitalizing on the spatial nature of AR and creating interactive techniques that require minimal direct interaction can prove to be beneficial for communicating information in architectural space. However, even though an AR system can afford to give users the ability to spatially interact with objects, there has not been much exploration in this area, and most provided interaction types and applications utilize more generic direct gesture and clicker based methods.

One of the crucial matters about the different types of interaction is the affordances. Affordances are the visual properties of the real world that are aligned with people's interaction and provide the link between the perception and action[3]. The visual combines the spatial affordances of AR and the natural movement, and not only can emphasize our main goal as an urgent one in architecture and information industry[4], but it also can reduce the amount of training needed for audience and enhanced usability, and adaptability, such as usefulness of these systems. The spatial interaction is one of the most intuitive interactions.

In this paper, the aim is to design a user interface in AR using spatial interactions to enable the communication of dynamic information in architectural space. Additionally, this paper is aimed towards the finding of a suitable application of proxemics AR in the spaces that need to transfer huge amounts of information in more appropriate ways. Selecting the museum as a case study at a place with a great amount of information can be presented as an example with its artworks. Museums have long relied on storytelling[5], it means that the information about one specific object came from different historical perspectives and all stories surrounding the object need to be recorded and updated

routinely.

Information can be saved to the objects simply by various forms of texts, photos, and sounds. However, the amount of data is growing at a high pace which needs to be recorded and updated continuously. More importantly, there are often very conflicting histories for objects, and the questionable histories of many ancient objects could provide a unique experience where alternative histories could be recorded and navigated as part of the installation. Moreover, a large amount of museums data, currently, are still able to create and tell stories. But very soon undocumented data will become just an "information noise"[6]. Finally, users have varying amounts of interests in information and with current systems, there is no way that we can have personalized information.

Based on the mentioned material, in the museum or places like it we need to deal with more and more detailed information about different categories of information. For instance, with regards to a specific sculpture in the museum, there are several categories of information such as the artist, history, background, style, material and so on. Also, for each of these categories we can provide more detailed information. For instance, on artist category, it can be only a name and date toward his background, other products or his style. So, clearly I defined these goals for my research:

- Showing information for different categories of information
- Showing information with different amount of details
- Use spatial and embodied interaction techniques

According to the mentioned material about the ability of spatial interaction in AR system, I came up with this hypothesis: Users can easily learn spatial interactions and they will use it to explore large amounts of information about objects.

To this aim, we describe the design specifications of an AR application for Microsoft Hololens, and android system. The AR application allows users to interact with objects and learn to explore information about objects using spatial interactions, including proximity to an object and orientation toward an object. It will apply the system to allow users to explore metadata about artifacts and sculptures in museums. In order to test the usefulness and usability of our system, it had been tested from different aspects, and then user study conducted on museum audiences. The users were audience of the museum as conventional users. They were interacting with objects and based on the results, we saw how the system can answer to the main goal of providing the dynamic information.

Also, in order to see how the system answers to the needs of the museum, I conducted a focused group study with domain experts of the museum as expert users. They mentioned the advantages and disadvantages of the system, and what is their expectation in a such system.

CHAPTER 2: LITERATURE REVIEW

2.1 Spatial Interaction

The idea of Proxemics was introduced for the first time by Edward Hall in 1966[7]. He described the understanding of people and using the interpersonal distance to regulate their relationship and interaction with other people. Based on his theory, there is a direct relationship between people's physical and social distance. He goes further to describe a variety of interaction zones and provides the exact proportionate distances for these different zones. Finally, his theory describes the spatial layout of different spaces and the way that 'fixed objects' and 'semi-fixed objects' can influence people's understanding of the space when they interact with it.

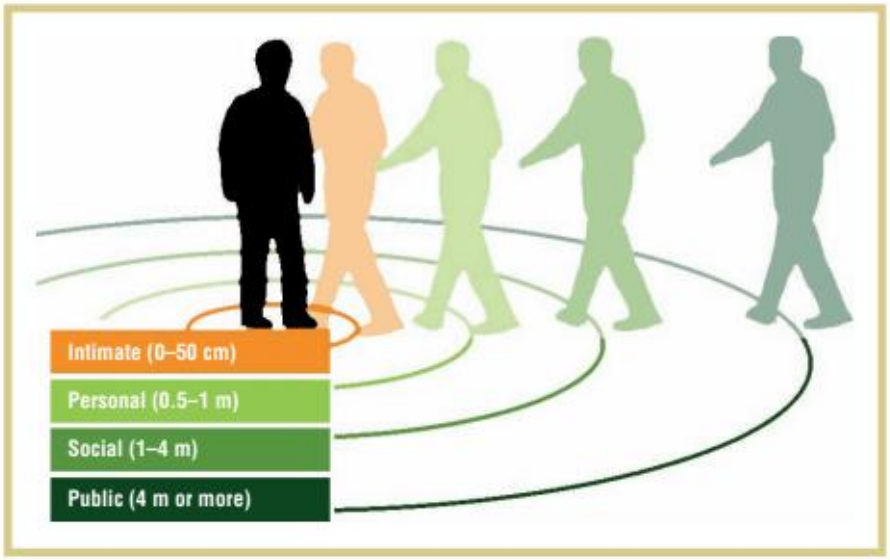


Figure 1: Edward Hall's proxemic zones [7]. Hall correlates physical distance to social distance between people and categorized it into four discrete zones.

The field of proxemics is nearly 50 years old (starting in the mid 60s). Even though it seems surprising that after more than 50 years from this idea, and with the advent of digital interaction alongside the idea of ubiquitous computing (Ubicomp), there is less

attention to the possibilities of proxemic interaction in this area. In the last decade, there were some researchers that paid attention to the proxemic interaction as a way that regulates the relationship between people. But, there is no research taken place solely about the spatial interaction as a way of interaction.

After about forty years from the idea of proxemic, Gellerson and his colleagues in 2009[8], described the spontaneous interaction of mobile users in the real environment. Spontaneous interaction is described as a central component of mobile and ubiquitous computing, but for taking advantage of this interaction, users must associate their personal devices, and devices encountered in their environment should be recognized. So, for recognizing the device in the relationship between human and environment, they present a spatial interaction. More specifically, Gellerson focused on the relative position of a character as one of the primary elements of spatial interaction. As a result, their research supported the connection between the network that identifies the device and their physical presence. The spatial interaction provides strong clues, which enable users to interact in a spontaneous manner. This is a great progress that now we can recognize other devices based on the network connection and spatial interaction. However, the recognition of these types of interactions between users could more readily be identified and it can provide a more complete understanding of the experiences of these users. Moreover, other characteristics of spatial interaction could enable them to scale their experiences and add the feature of scalability.

Along with Gellerson, Greenberg and his team also address the use of proxemic interaction in their research in 2010 [9]. Greenberg has more than 6 articles about the importance of the spatial interaction, in which they all address the question: How important

are spatial relationships to proxemic interactions? Their research primarily describes the necessity of understanding the spatial relationship of people with surrounding digital devices. People mediate their relationships based on their posture, distance, and orientation, and this spatial information enables them to interpret and interact in distinct ways. These factors play an important role in regulating interactions among people. Greenberg did a great job in defining the importance of the spatial interaction in the arena of the digital interaction. However, he did not look at the spatial interaction as a way that we can combine the information presented through digital devices. It is a great progress that the digital devices regulate themselves based on spatial interaction with users, but it can be more and it can take advantage of this interaction for providing more information. So, they put their focus on the spatial relationship and provide a prototype that can regulate the implicit and explicit interaction techniques.

In 2011 Greenburg upon this research defines a proximity toolkit and describes the different components and its usage[10]. Firstly, he explains the importance of proxemic interaction that can bring the ability for people to naturally regulate their relationship and use it on a day to day basis. In his previous research, he describes the proxemic interaction in the digital area. However, he tries to solve a technical problem which is one of the main issues with spatial interaction. For having the spatial interaction with digital devices, having a prototype that can solve all necessary technical aspects is very crucial. It is challenging to understand the proxemic information from sensors. They provide a toolkit to solve this problem, and it is a room-sized environment that consists of various components. They define key proxemic measurements as:

- Orientation: the relative angles among the objects; it can be the different angle or same angle between users or the user and the object / digital device.
- Distance: the distance between entities.
- Motion: changing the distance and orientation over time.
- Identity: knowing the user or device that users interact with it.
- Location: based on Edward Hall[7] the features of the environment the same as the location of fixed and semi-fixed features.

By defining these measurements, they try to address all of them in their proxemic toolkit. It is a huge step that enables designers to have a rapid prototyping mechanism for identifying this way of interaction. However, the limitation of spaces is one of the factors that needs to be addressed. Designers cannot have a scalable environment, and they need to stay in a room for their exploration. Moreover, if you want to add just one more component to the interface, such as head angle, it is impossible.

Moving forward from Greenberg, there is extensive research done recently that provides a focused attention on specific parts of the proxemic interaction. Paul, C. L., and Bradel, L, 2018, talked about a specific item in the proxemic interaction.[11] When we are looking at the proxemic interaction and spatial relationship, we need to look closer at different aspects of it. For instance, this paper specifically focuses on the importance of the display size on the interaction. They found a relationship between the different interaction zones and the relevant display size based on the distance between the user and the display. Based on Hall in 1966 [7] they used his proxemic dimensions to recognize the interpersonal distance for interaction: *"intimate (15-46cm), personal (46-122cm), social (1.2-3.7m), and*

public (3.7-7.6m)". They describe different display sizes relative to an average participant height.

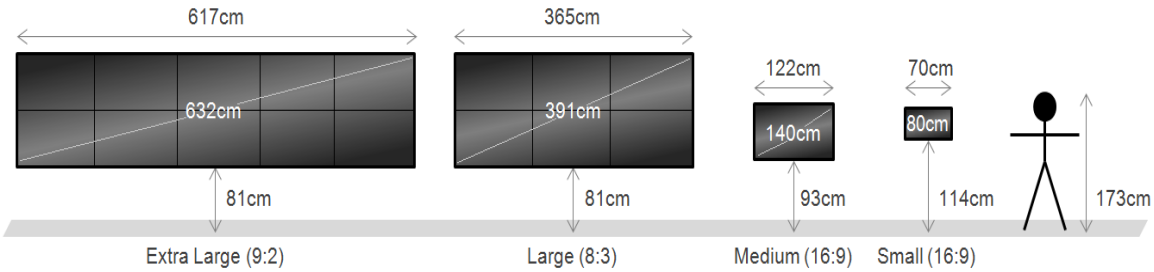


Figure 2: The relationship between the physical distance of user form the screen and the screen's size

Over time, with the use of proxemic interaction, a theory of proxemics as they apply to, HCI researchers try to use these definitions in interaction design and to define the problems and attempt to address them. One of the important aspects of it is the clarity of information that users can receive from the information. There is a direct relationship between the distance of the user to the screen and the amount of information that is presented. Thus, if a user is far away from the screen, he can see little information presented in a big screen in a large enough visual format, but when he moves closer he can see a smaller screen with more information.

2.2 AR technology as a tool for providing the information

The major use of AR in architecture is related to the application of it in the design process, construction, and post construction. So, there is a potential usage in various aspects of design process, including design collaboration, construction, visualization, renovation, and education [12]. Moreover, the AR system can be used in an outdoor environment from the designing stage to modification and the presentation to the clients. It can bring up a real building on the site location, and make it possible to see the building with all of its

surrounding environment [13]. Most of these mentioned materials are focused on the AR as a way for presenting the building. However, there is less attention to the AR as a medium that can link the information to architecture.

Wayfinding is one of the applications of the AR tool, specially in indoor spaces that we do not have access to GPS and there is a great amount of information that need to be transferred to users about different spaces. “An Augmented Reality Museum Guide” [14] is the name of research that is trying to address this problem with the help of Augmented Reality’s guide points in the museum context. With the help of their system, users can use their cellphone’s camera in exact locations to receive information about different spaces for exhibitions and the guidance that can guide them to these locations.

There are some new approaches to the AR in architecture, for instance, He et al. [15] have researched the use of augmented reality as a marketing tool in a museum as a way to motivate users to interact more and make them interested to buy the objects. They are describing a direct relationship between the user experience and willingness to purchase items. They also find AR to bring a unique user experience that is engaging for users. Based on their experience at the museum, attention, interest, and engagement, these are 3 primary factors that have more effect on the user experience. AR has the ability to trigger these three main factors.

More than marketing, there are a number of potential usage scenarios for augmented reality to provide more information for users. One of these cases includes cultural and heritage tourism[16]. Cultural heritage sites are one of the most popular tourists destinations. Tourists like to know a great deal of information to gain knowledge about all the rich historical, cultural and architectural aspects of these sites. There are two

specific limitations for presenting information in this context. First, there is no way to access the original physical structure, people lived at those eras. Also, these sites are most of the time under natural degradation and changing gradually over time. This research has described AR technology that can move beyond time, space and language barriers to present the information.

HoloMuse is the research that is trying to enhance the engagement of users with archeological artifacts through gesture based interaction, which happened through Microsoft Hololens[17]. Users have the ability to see real objects in exhibition's context, and with the help of HoloLens they can bring a set of related virtual objects in their field of view. So, being in the real context and gaining more information about similar works with the capability of interacting with virtual objects, such as rotation and scaling, are the advantages of this system.

The MIT Museum Glassware Prototype[18] is one of the most recent research projects that has been done on this area. The main focus of this research is on designing a smart glass that enables museum's users to gain information about objects in a more interactive and engaging way. It is a voice command interaction that enables users to select one of the provided options and gain information about that category on the top layer of a real object as virtual information.

Also, Avraam, S., Hatzipanayioti, A., & Avraamides, M. N[19] are talking about the augmented reality and spatial interaction. With the invention of new technologies, such as virtual reality head-mounted tools and augmented reality glasses, we have new types of experiences in the spatial environment. So they are going to answer this question: how

similar is the spatial interaction and memories from these new tools to those achieved through direct experience with the physical environment.

It seems, still several features of AR application have not yet been researched. There is not enough research projects done about different types of interaction in AR, and providing the protocol that suggests the proper interaction type for different purposes. For instance in a public space such as a museum, it would not be appropriate to interact with the virtual object that only you can see with the gesture and your hand movement, or in a place like a library it is not proper to interact with voice commands. It is obvious that with having knowledge about all available types of interaction, it is easy to have a user study for a specific purpose. However, we do not link the proxemic theory and ubiquitous computing with AR technology. It means that spatial interaction needs to be more examined.

CHAPTER 3: METHODOLOGY

This thesis will study a proxemic user-centered approach to design AR interactions for communicating information in architectural space. To achieve this goal, first I designed a prototype AR environment for Microsoft Hololens depicting different interaction types that utilize spatial interactions. Next, I conducted two user-studies to understand the advantages and disadvantages of this system over traditional ways of conveying information and how it works. In the next part, I summarized the results of the user studies to see how successful it was to address all problems I tried to solve and how I am close to prove my initial hypothesis. Meaning that to find which part of the system works based on my expectations, and which part need to be redesigned. Also to find out what are some results that I was completely unaware of and that need to be addressed in future works. Ultimately, based on the results I found in the user studies, I will talk about future works that can be done to improve the system in both areas of solving problems and usability.

This study has different components that I try to explain in the following order. First, I will talk about all technical components of the system and how they work together. Next, I will talk about the system design and how it looks like; I will try to show the visual aspect of it to make it more clear and tangible. And then I will talk about the user study itself and all details related to it.

3.1. Technical implementation:

I have used Unity, a cross-platform game engine that enables me to model virtual objects and position them in the real environment. Unity is free for educational purposes and it best works for the interactive contents. Also, students can receive their free licence

by its website[20]. It is completely adaptable with the interfaces I am trying to work on, such as Microsoft Hololens and Android systems. More specifically, it supports 2 programming languages, C# and JavaScript. Also, it has a strong documentation process on both of them.

For AR devices, I have used Microsoft Hololens that is known as the first self-contained, holographic computer. It enables users to interact with high-definition holograms in the world. As a specialized element, Microsoft HoloLens has components that enable holographic computing. All of these components and more enable users to move freely and interact with holograms[21], while keeping in mind that the results of my study are not bound to a specific device. And as I moved forward in my research, based on the results of my user study, I decided to test the exact system and interface with Android system for my second study with domain expert to see what is their idea about both platforms.

For programming purposes, I have used the C# language on Visual Studio IDE from Microsoft that is completely adaptable with Unity. More specifically, for Microsoft Hololens, I used Mixed Reality Toolkit-Unity [22], which is a Microsoft driven open source project that uses codes from the base Mixed Reality Toolkit repository and makes it easier to consume within Unity.

Figure 3: The technical components of the system

3.2.Design:

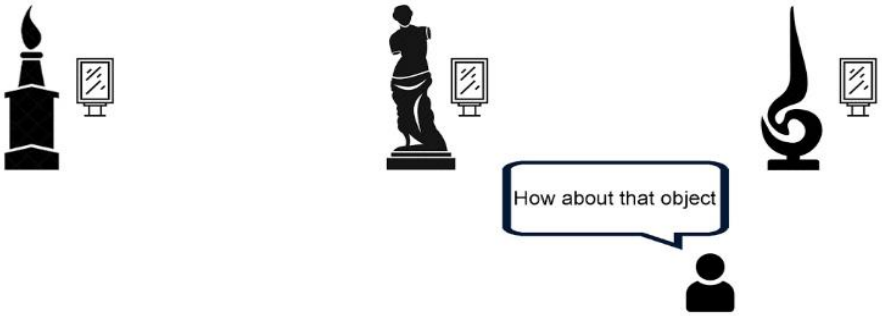
The main purpose of this project is to provide information about specific objects in a novel way that is more engaging and interesting. So, there are three main components in this system, which are user, object and information.

Based on these mentioned materials, I am looking at spatial interaction as a way to transfer information to users. For finding what aspects of information is important and how I can link them to the spatial interaction I draw a storyboard diagram to make it obvious. For instance, I am in a museum with multiple objects. I will become interested in one of them and I want to know more about it. Who is the artist, and what is the style behind it? I see a panel beside the object, so I move closer and read the panel. However, it is not enough for me and I am looking for more information. What is the related objects, and what are the artist's other works? So I want to expand and alter the information. Based on the mentioned material, I introduce 3 main elements of information in this way: different categories of information, more detailed information, expand and alter information. I link them to three different spatial interaction. The first one is user's distance from the object. The second one is rotation and orientation of the user toward the object. And lastly, the head angle is dependent to the user's head movement.

First step

Figure 4: Story board, what a user expects to see in the museum

Second step



Third step

Figure 4 Continued

In the following part, I will try to make a connection between three interaction and three desire aspect of information, also I will visually show how the system tries to address these interactions.

- Distance: the amount of information presented to the user will be changed based on distance of user toward object. According to Hall [7], in a spatial interaction there is a direct relationship between distance, size, and the amount of information. In this study, when the user gets closer to the object, he/she can see more information. The way it works is when the user gets closer, more detailed information about a specific category of the object becomes visible. The font size decreases, so in a similar panel the user can see more, and because of the close distance he/she has

the ability to read them. So, there will be a direct relationship between distance and the amount of information moving closer.

Based on the volume of detailed information decided by designers, they can divide distance by different numbers. It can vary based on the size of space and the amount of information that will be presented. For instance, the following diagrams show how this system works in a study where distance is divided by four areas.

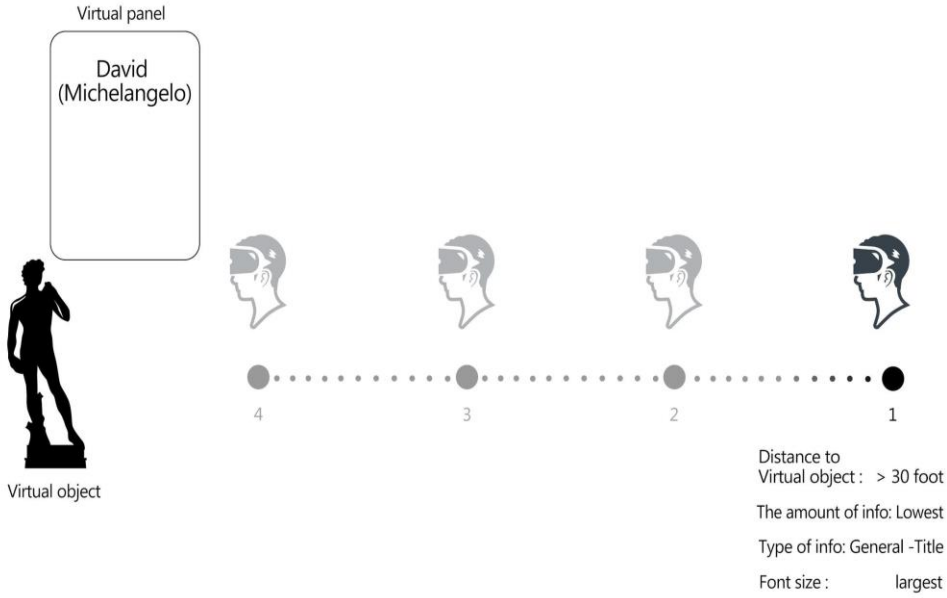


Figure 5: What a user sees from long distance

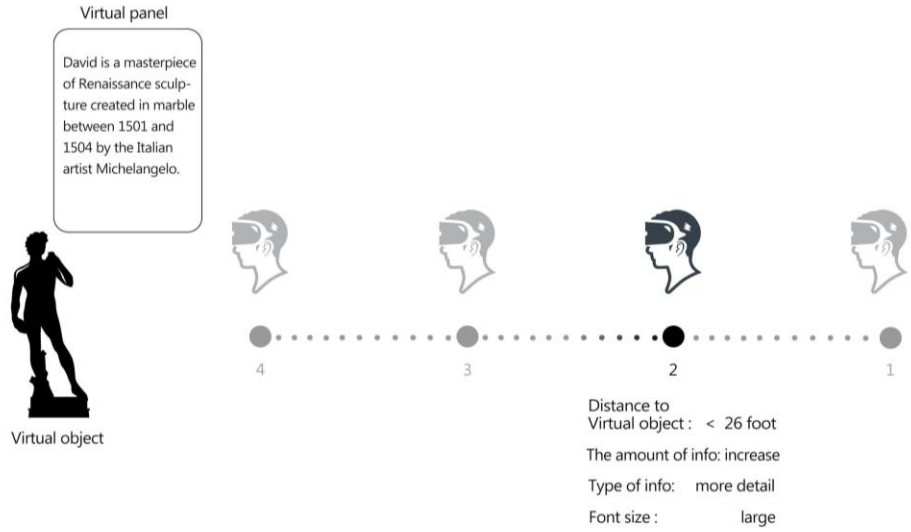


Figure 6: What a user sees from short distance, moving toward the object

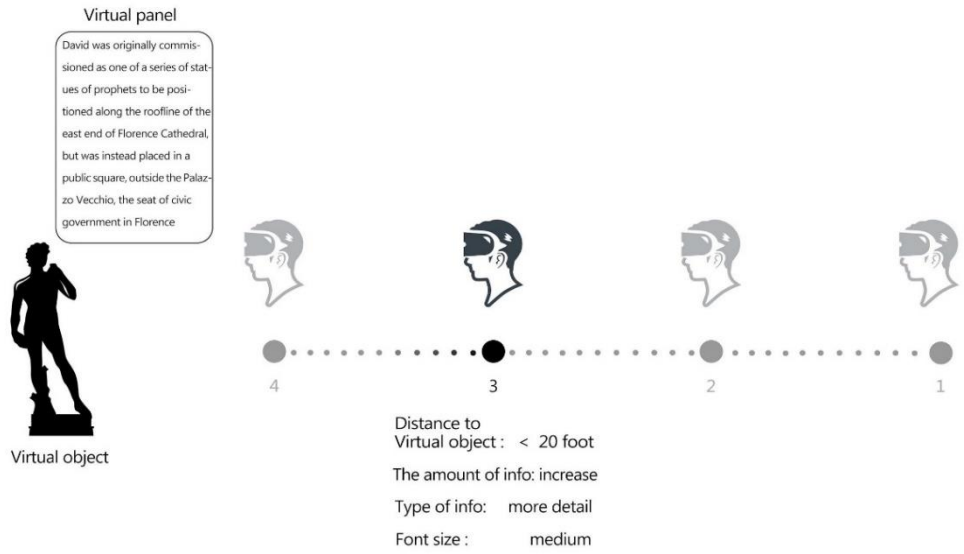


Figure 7: What a user sees from a shorter distance, moving toward the object

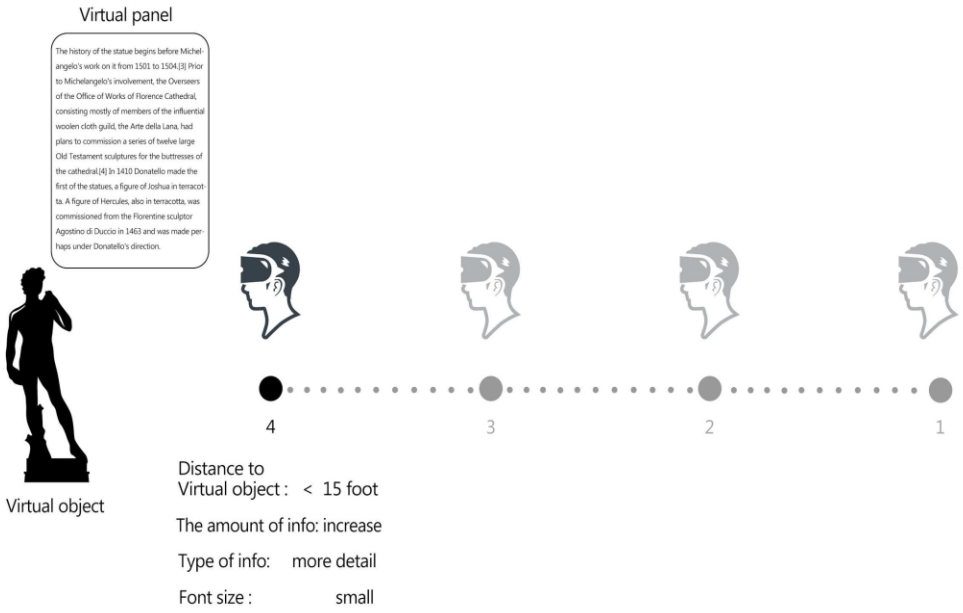


Figure 8: What a user sees from the shortest distance, moving toward the object

- Orientation: when users rotate around the object, they can see different categories of information in a different location. More specifically, I defined a vector between

the user, Hololens, and object, which is predefined and is the basis for my calculation. Then, when the user starts interacting, moving, and rotating around the object, a second and temporary vector will be created. The system will be updated by subtracting the angle between temporary and predefined vectors, which I named User's Location Degree.

Based on the number of categories that I like to show about the object, I can divide the area around it by that exact number of categories. So, when user's location degree reaches that angle, the category of information will be changed. For instance in following diagrams, if my object is presented in front of a wall, I have 180 degrees in front of it. So, if I want to present 3 different categories, when the user passes 60 degrees, the category of information will be changed.

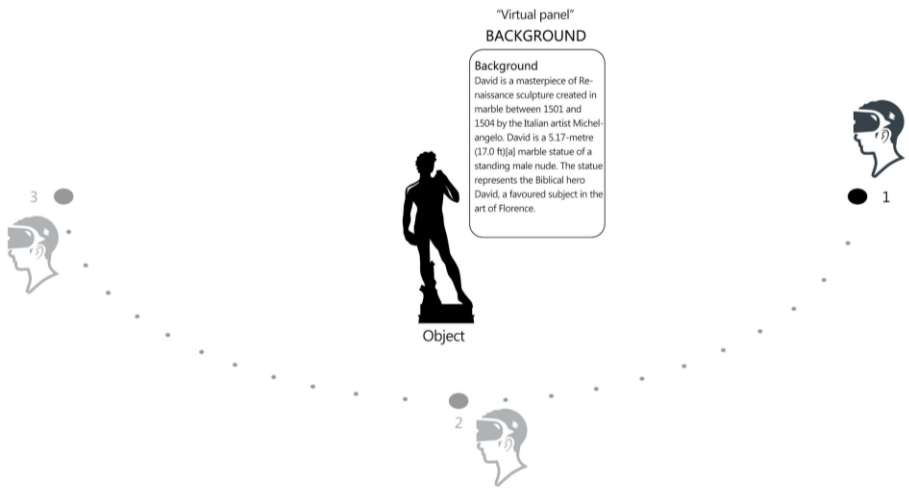


Figure 9: What a user can see in a specific location, based on orientation around object

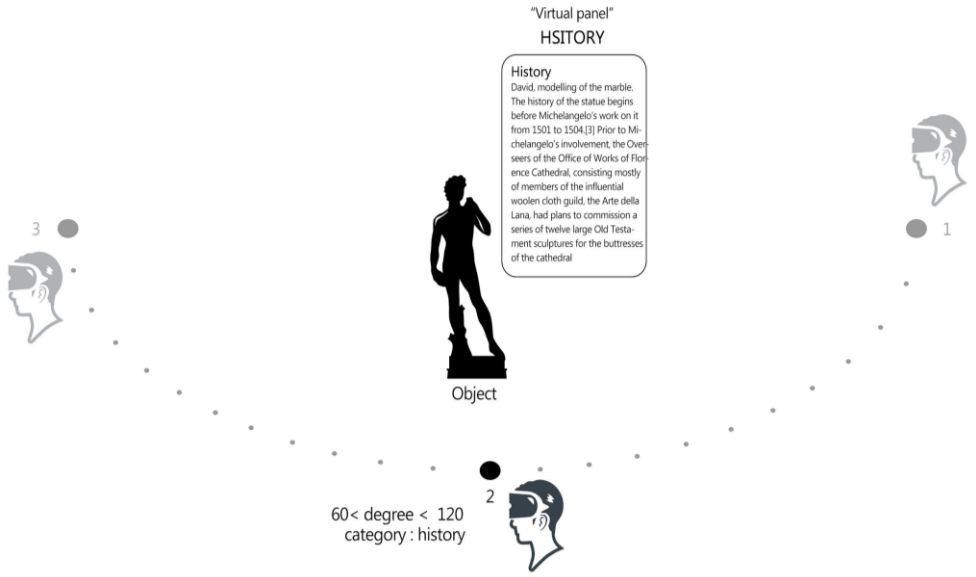


Figure 10: What a user can see in a specific location, based on orientation around object

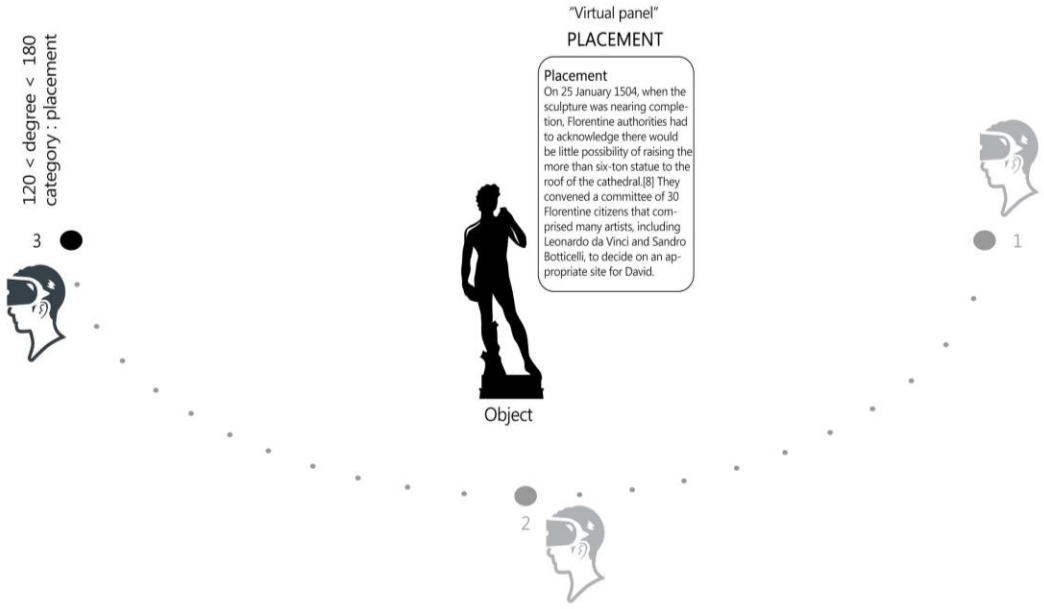


Figure 11 What a user can see in a specific location, based on orientation around object

- Head Angle: this interaction is based on the angle between user's horizontal viewpoint and the Z axis. The same as orientation, I defined a vector between the user, Hololens, and object, which is a predefined vector and is the basis for my calculation. Then when the user starts interacting and moving his/her head up and down toward the object, a second and temporary vector will be created. The system will be updated by subtracting the angle between temporary and predefined vectors, which I named User's Head Location Degree.

  If the user looks up or down, and the user's head location degree goes over the exact number, information will be changed. This information is on the same category, but it provides more information or shows a second alternative about that category.

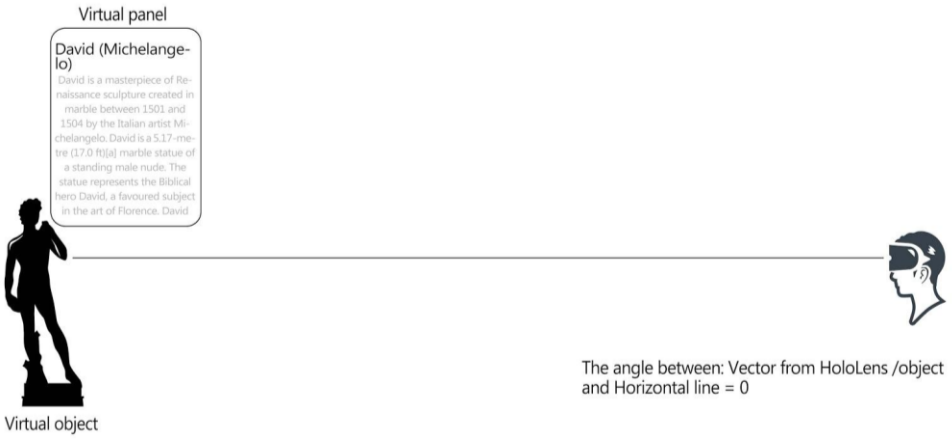


Figure 12: What a user can see when he does not change his head location

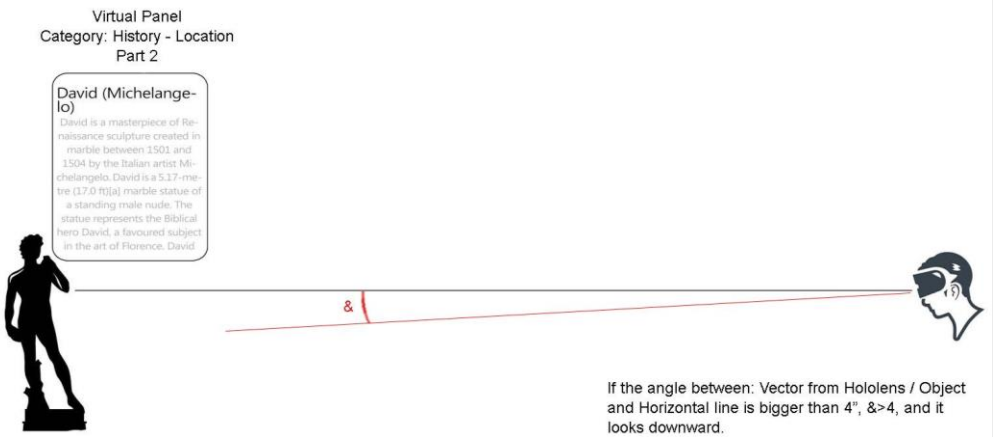


Figure 13: What a user can see when he looks down

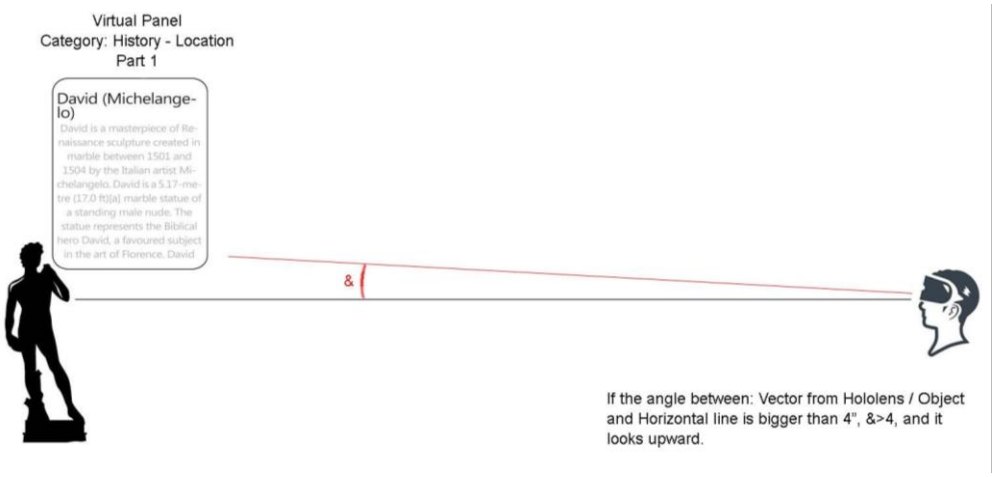


Figure 14: What a user can see when he looks up

All of my calculation is based on the coordinates I can get from the object and my devices. The location of the camera in Hololens and the Android cell phone becomes the coordination of the user. In the case of Hololens this location is the user's head, and in the cell phone it becomes the user's hand. Also, the object in the 3d space has coordinates, so I can calculate the distance and the angle between user and object.

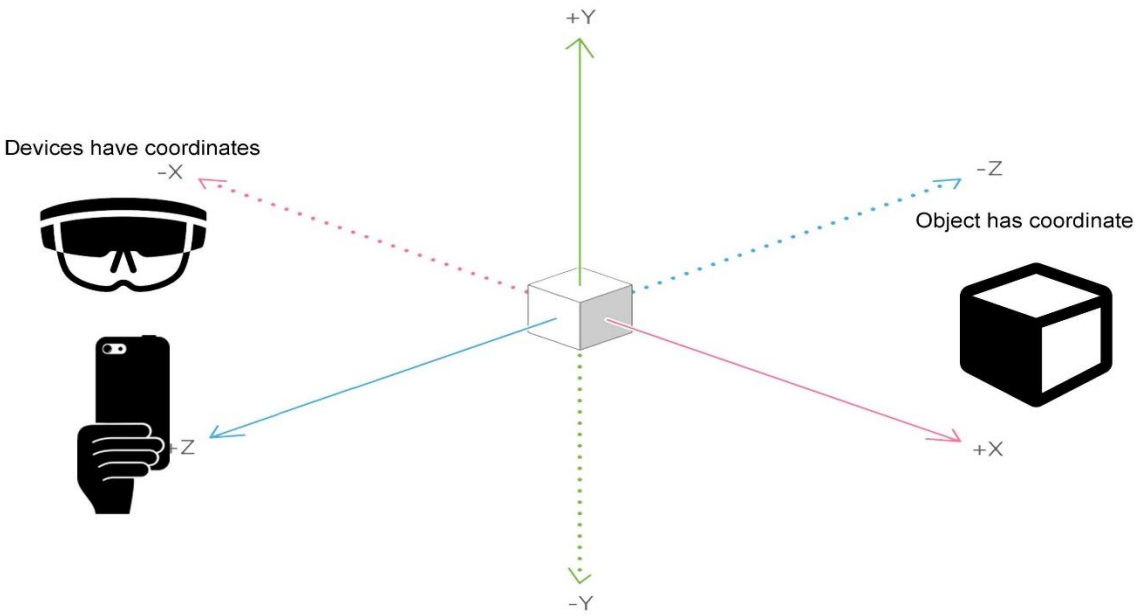


Figure 15: The 3d coordinates is the base of the system's calculation

This system has two main signifiers, which look like navigation maps. The first goal of these signifiers is to instruct users on how they can interact with the system, and also shows what they can expect to see in different locations. Another goal is to make them aware about their location in the system and give them some idea about what they can find in this location and how they can move to another area for different information.

The first signifier is a virtual map that will be presented under a real object and is divided based on the number of categories. It can vary by color, and also a text will appear on each item that shows the title of that category. Both color and text are aligned by the main panel that shows information, so the user can find the relationship between them and figure out the way he/she can start interacting with the system. The following images are examples of 3 categories of information that will appear under the object.

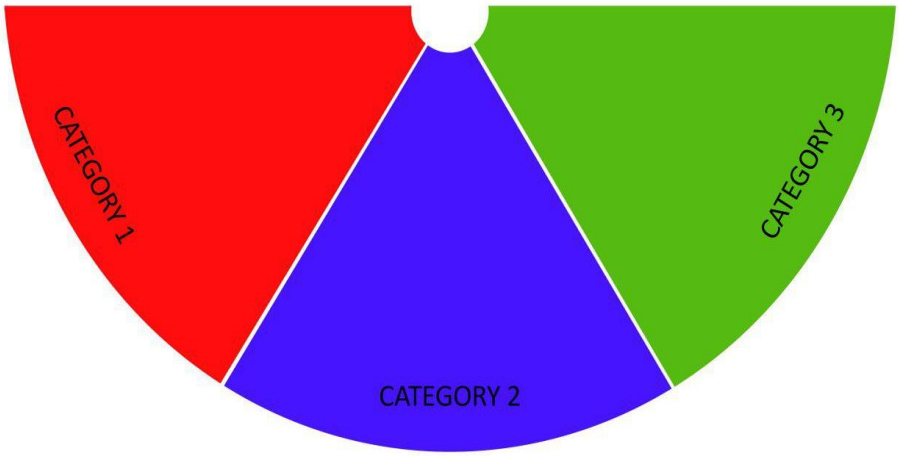


Figure 16: Three different Categories virtual map that will be shown under the object

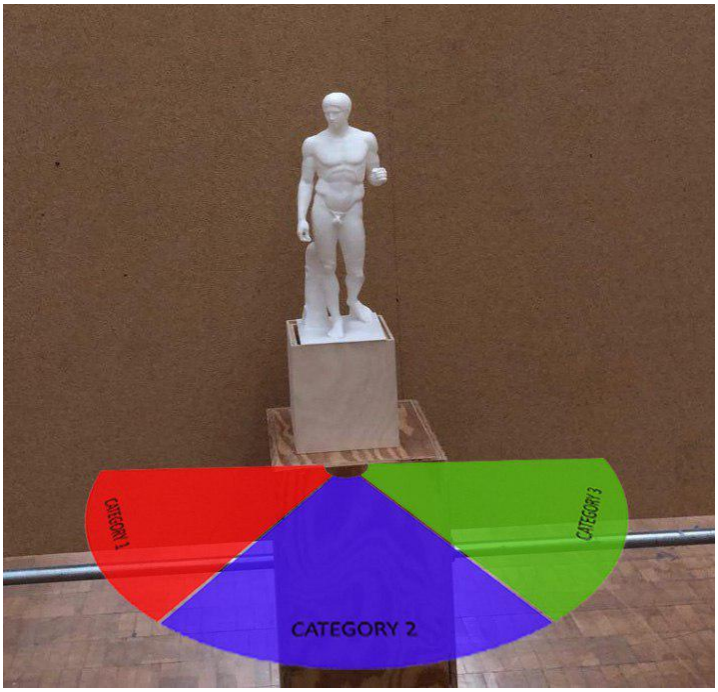


Figure 17: How the virtual map looks like under the object

The second signifier will appear on the top left side of the main virtual panel. It is completely based on the number of categories and the number of distance steps. It will show users their location in the system and what they can expect to see there. All pieces are in gray and only one of them is colorful, which shows the user's location. The color varies based on the color of the category. Also, the color thickness shows the stage and amount of information they can expect to see. The following diagram shows the system with three different categories and each level has three levels of detailed information.

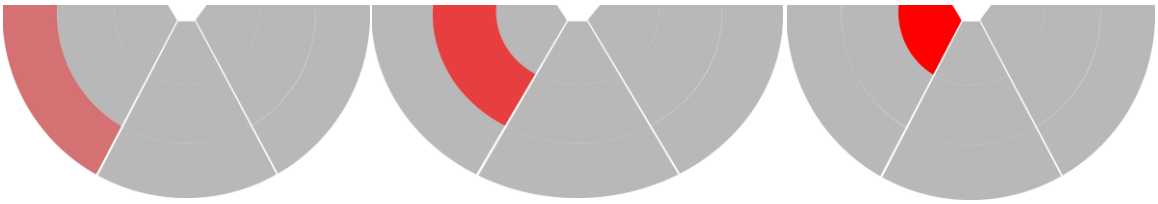


Figure 18: The three level of detailed information used to give user idea about his/her location in the system, on the first category

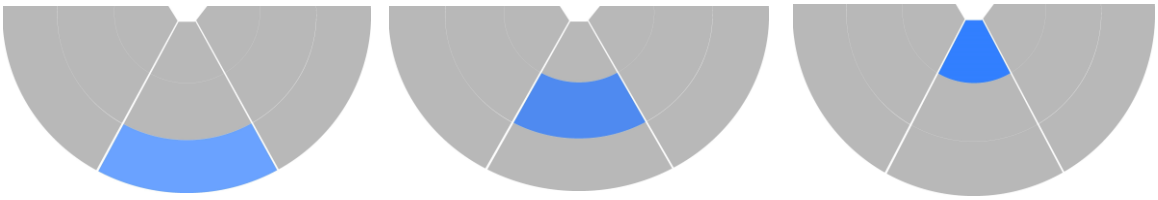


Figure 19: The three level of detailed information used to give user idea about his/her location in the system, on the second category

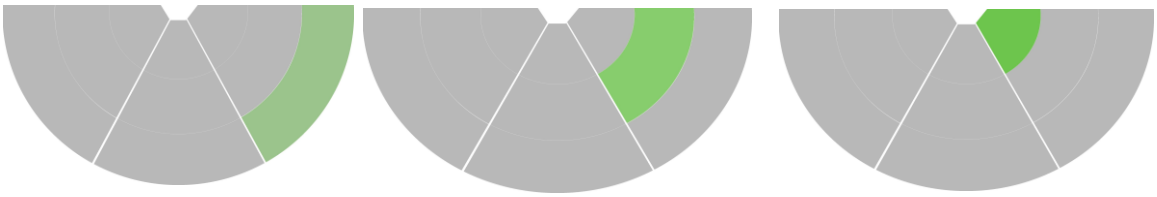


Figure 20: The three level of detailed information used to give user idea about his/her location in the system, on the third category

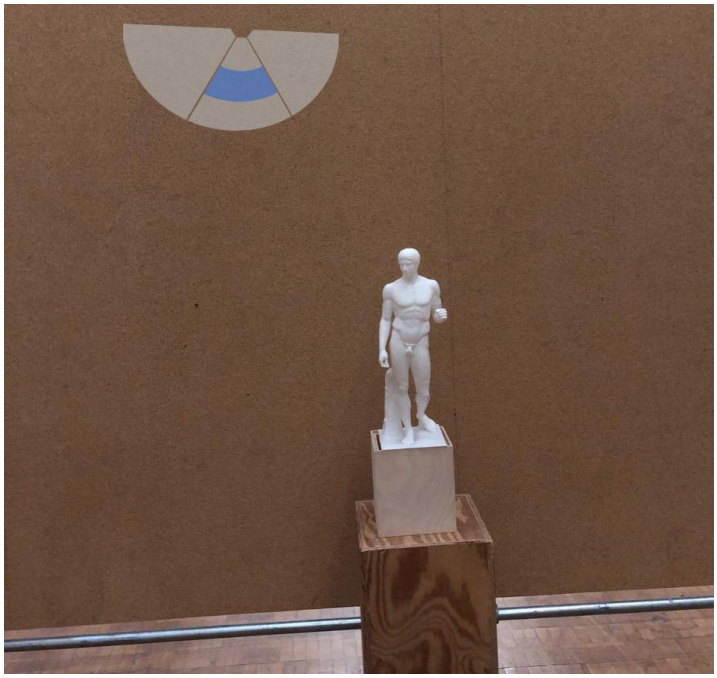


Figure 21: How the navigation map looks like on the system

The main component of the system is a panel that makes me able to put all related texts, different categories, and different stages inside it. It is a simple virtual panel which appears on top of the object, and it gives users the ability to see information at the same time of looking at the real object. The title text is colorful and its color is based on the category of information it presents, there Color coding mentioned as one of the way that increase the learnability of the system and help user to find the relationship between the different features by the same color [23]. Furthermore, this panel is in front of the user's eyes at all times without the dependency to location or orientation. It always regulates itself to create a perpendicular view for the user.

3.3. User Study:

I selected the museum as a case of the space that I am trying to test my system, because it has the ability to present information in a way that I am looking for. It enables me to provide information about art pieces in a novel way through an AR device based on spatial interaction. I have this opportunity to have this study in the Bechtler Museum of modern art in Charlotte, North Carolina.

The Bechtler Museum of Modern Arts in Charlotte, North Carolina, is a 36,500-square-foot (3,390 m2) museum space dedicated to the exhibition of mid-20th-century modern art.[24] It has an exhibition in the second floor that started from 02/01/2019 and continues presenting to 08/01/2019.

Figure 22: The Bechtler Museum, gallery of modern art

This space has one more advantage that is very much aligned with one of my device's main limitations. For Microsoft HoloLens, I need to regulate the amount of light inside that space. The brightness of the virtual object in Microsoft Hololens is limited to a specific amount and is better to have the user study in a space that is not exposed to a huge amount of natural or artificial light.

My models were two pieces of art. One of them is a sculpture and the other one is a wall art. I tried to implement the study on these two types of art pieces because, firstly I had the aim to see the movement of users in the space when they are interacting with more than one object, also these two piece's type are the most popular ones in different exhibitions within the museum context, sculpture and wall art.

The sculpture is a 2/2 Two Two-Part Pieces. It is a cube with opposite sides removed. It is an example of the artist's, Sol Lewitt, conceptual ideology in art making. Lewitt would create templates for his works such as this sculpture, but the responsibility of implementation fell on an impersonal third-party. This object was designed by Sol Lewitt and then fabricated by a metal worker.

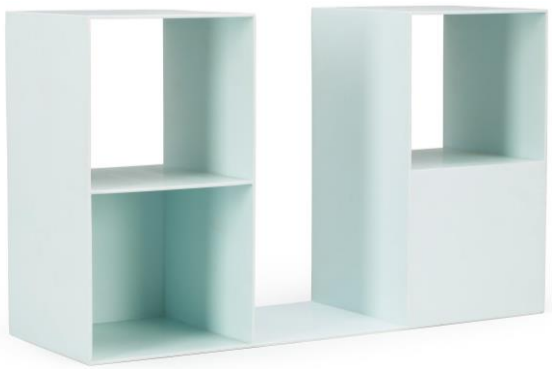


Figure 23: 2/2 Two Two-Part Pieces, it is a Cube with Opposite Sides Removed, Sol LeWitt, 1968

The wall art is a untitled porcelain relief. We can see the artist's, Pasmore, exploration in fresh mediums and abstraction. Having been influenced so heavily by the geometric stylings of Paul Klee, the non-figurative work of Piet Mondrian, and the playful exploration of form in the Surrealists, we have a fantastic example of the amalgam that made Pasmore's work this unique in and of itself.

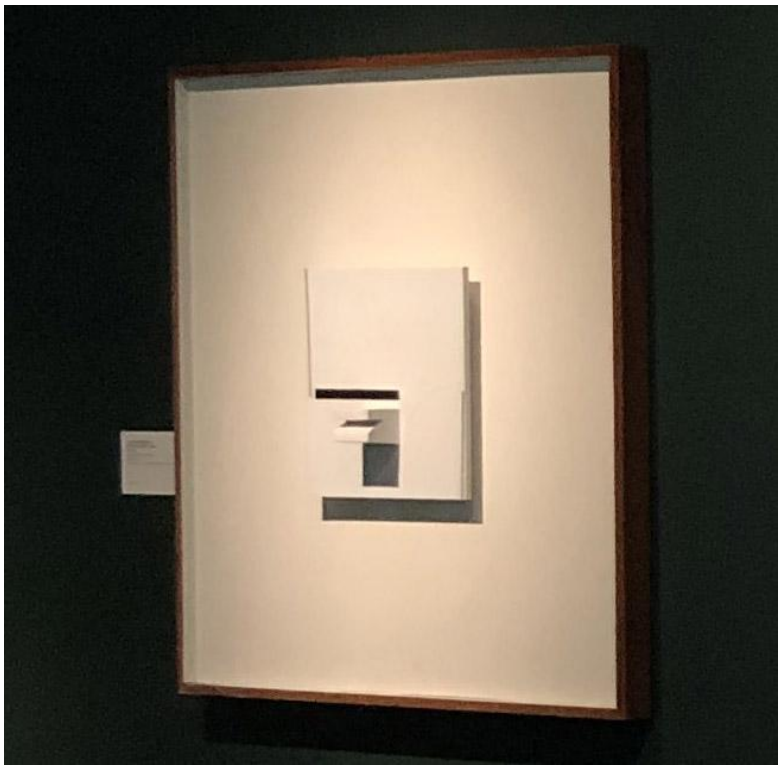


Figure 24: Untitled porcelain relief, Victor Pasmore, 1967-1968

My system provides 3 categories of information about each piece: artist, object and style. User can see the information related to the artist on the left side of the object. In front of the art piece the user can see the information related to the object and on the right side he/she can see the information related to the style of it. Each category will be divided to 3 steps as the amount of information. First step, which is the longest distance toward the object, provides a high level information about it, such as the name of the artist. Toward the object it provides more detailed information about each categories. For example, in the artist category, user can see other productions of the artists by their images on the closest part to the object. In each step of the distance and category, user has the ability to switch information with his/her head angle. There are 2 different options for each of them that user can toggle with his/her head.

I did 2 user studies. The purpose of the first one is to test the usability of the system. I wanted to see how well my system performs and because of that I did the usability study. On the other hand, the goal of the second study is to find out how useful would the system be for museums and in this case I did a focus group study.

3.3.1. Usability Study:

In this research, I tested different types of spatial interactions through augmented reality tool. The affordances of these types vary. With the help of this user study, it will be possible to understand advantages and disadvantages of each type. I asked my users about their best interaction types and how it works for them. Specifically, I wanted to find answers to these questions by running this user study:

1. Can users learn the 3 provided spatial interaction techniques on their own?
2. Will they use the interaction techniques to explore information about both objects?

For doing this user study, I submitted an IRB under this topic: Testing different augmented reality interactions in architectural spaces. It got approved with the Reference ID: 177255. The procedure of the usability study:

1. Signing the consent form: all of my users needed to sign a consent form before start interacting with the system, Appendix A.
2. Brief introduction: The purpose of the introduction was to tell them we are testing the system and not the user, so any problem or flaw is related to the system and not them. Also, I warned them not to touch or hit the objects in the museum. Because of the goal of study, I did not explain the 3 different interactions, nor provided any tutorial about how to use the tool.
3. Study with Microsoft Hololens: they used the Microsoft Hololens as the AR tool. Also, I asked them to use the think aloud technique, and they mentioned all problems, exploration or achievement that they gained through the study.
4. Post Questionnaire: after the study, I asked them to fill a short questionnaire for me, Appendix B.

For doing this study, I asked for the participation of graduate students at the school of architecture, University of North Carolina at Charlotte. In total, I had eleven users. None of them had previous experiences with my tool, Microsoft Hololens. I considered them as regular visitors of the museum. The approximate time that they spent on the user study was 30 minutes for each user.

After the study I had 3 different sources of data, which I started looking at them and analyzed all of them qualitatively.

1. Think aloud technique during the study: I transcribed all users thoroughly about the system, Appendix C.
2. PoV Videos: I asked to record the point of view of my users during the study in my IRB. Hololens gives the ability to record its point of view camera. I looked at all observations and mapped the movement of my users. Appendix D
3. Post Questionnaire: Analyzing the questionnaire and finding results, Appendix E.

3.3.1.1. Usability study results:

I went through all of the mentioned data to specifically see how my users answer the two prior questions that motivates me to do the usability study I mentioned in the previous part. For analyzing my usability study, I got inspired by Nielsen[25] five quality attributes that assesses how easy my users interact with my interface. I specifically selected 3 of his five attributes that was directly related to my study: learnability, errors and satisfaction. Based on these attributes, I tried to see how my users interact with the system.

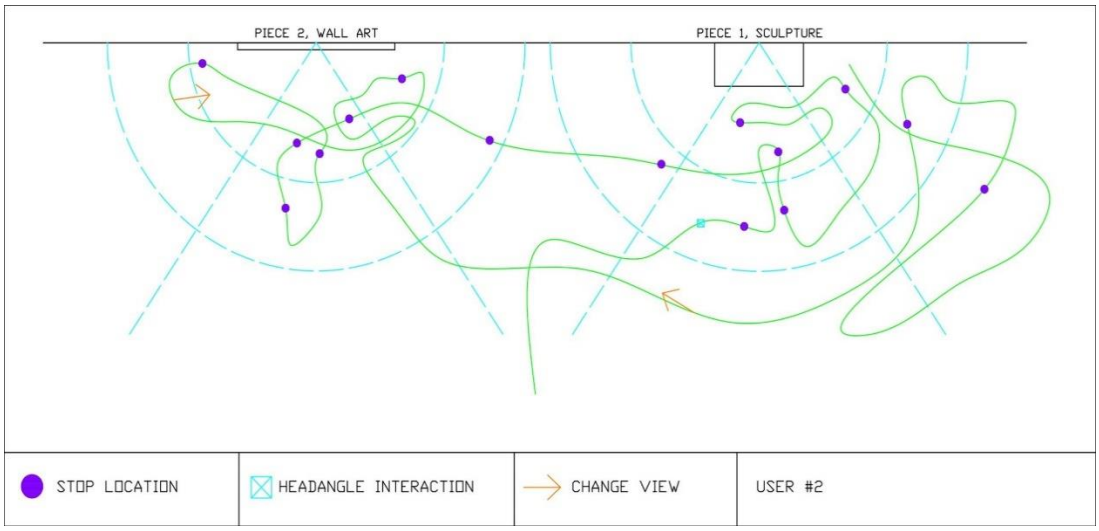
3.3.1.1.1. Learnability:

I initially tried to see whether the users can learn the 3 provided interaction techniques on their own or not.

- Distance: Users can receive more detailed information by moving closer. All users easily discovered this interaction.
- Orientation: Users can change the category of information by rotating around the object. Most users discovered the orientation, but found it less intuitive than distance.
- Head Angle: Users can switch between two different available options by looking up and down. Only two users out of eleven discovered the head angle.

Specifically, I can find two patterns of learnability based on the users movements.

1. Some users tried to know more about the objects, also tried to explore more in the provided information. They moved around two objects continuously and their stop counts were higher than other groups. The following 2 maps below show samples of user movements in this pattern.



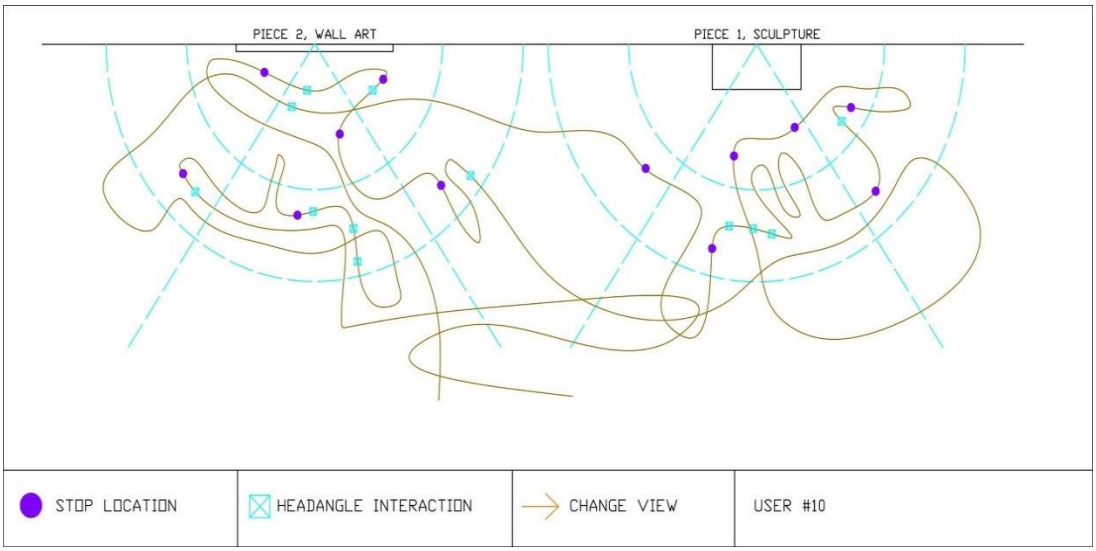


Figure 25: Two sample movement maps for the first learnability pattern

2. Another pattern of learnability is testing the interface. This group of users tried different interactions several times and it looked interesting to them. They had several quick movements between different information zones to figure out how the system works. Meanwhile, they started gaining information about the two objects. however, they had less stopping locations than the first group. Following maps show two samples of their patterns.

Figure 26: Two sample movement maps for the second learnability pattern

All of my users, except two of them, did interact for both objects and gained information about them.

There are some interesting points extracted from my observation that I can put them under learnability analysis. Firstly, Only two users found the Head Angle interaction and both of them were looking for left and right head movement interaction after finding it. Also, Two users were looking for some Gesture Based interaction during the study. Lastly, Two users were looking for some interaction between signifiers and panel.

3.3.1.1.2. System Errors:

There are several points that users mentioned during the study or in the questionnaire. The most important complain was about the situation awareness when wearing the Hololens and interacting with the system. They thought it was possible to bump into other objects or people when they were wearing the Hololens and interacting with the system. The next major complain was about the tool itself, the Hololens. I received some comments about it: *"The lens was heavy", and "Not friendly to people wearing glasses.", "The text was blurry",* and *"limitation of view in Hololens".*

Moreover, they had a suggestion about two signifiers. They said it would be great to introduce them at the first stage that can clear the system for them immediately. *"The diagram showing the user position needs to be more clear and bold".*

3.3.1.1.3. System satisfaction:

There were several appreciations about the system. They generally liked the idea. The main comments was about the dynamic information and how they could receive information in an interactive way that enables them to find more information about objects. Also, they were really satisfied with the interesting way that they could interact with information and the more time they can spend in the museum in more engaging manner. Moreover, they really liked the multimedias added to the system, which enabled them to

see the artist's picture or other related object pictures alongside the information.

3.3.2. Focus group, domain expert:

After the usability study, we did a focus group study with domain expert. Based on some of the initial comments I received on our usability study, we added an alternative to our tool. We deployed our system on android system, so users had the ability to interact with both the Microsoft Hololens and Android cellphone. More than it, the cellphone can recognize the QR code under the object, and immediately after the recognition, the virtual panel appears and user can start interacting, with having QR code in the future study we can have multiple objects with their individual QR code.

The goal of this study was the usefulness of the system for museum. specifically, I tried to find answers for these question:

1. What is the advantages and drawbacks of the system?
2. What are the design problems?
3. What are they looking for in such a system?

For doing this study, we invited curators of the Bechtler museum for this purpose. We had 3 curators, and focus group study took about an hour. Firstly, we gave them a brief introduction about the system and its purpose. Then, we gave them a demo with both devices. They had the ability to use and interact with both interfaces. At the end, we had a conversation about their idea and specifically we tried to find answers to our questions. I transcribed our conversation and it became the source that I analyzed, Appendix F.

3.3.2.1. Domain expert results:

Based on our conversation during the demo time and the conversation after, I extracted these result that are the answers to our primary questions:

- They overwhelmingly supported the idea. Specially, they were interested in the interactive way that we can provide more information about pieces of arts. Also, they were really interested in the way that people became more engaged and it could force users to spend more time during their visit.
- They found the system too complicated, suggesting to simplify the interactions.
- The found the mobile interface more convenient, because it is less distractive. They thought users can have more situational awareness, and it will decreases the chances of bumping into the other objects. Also, they thought that museums do not want to spend lots of money to buy such a system, Hololens, and also spend even more for maintenance.

Moreover, they had some suggestions about the system:

- They thought it is better to combine direct and spatial interaction together. It is a great opportunity to have personalized information. They were really interested in distance interaction for finding more information, so we can select the category with a gesture based interaction, where with moving close we can gain more information.
- Bring more background information about the piece of arts in the way that user understand the context that object created.

CHAPTER 4: DISCUSSION

In this research, I proposed an AR interface that utilizes spatial and embodied interactions with the goal of creating dynamic spaces that are integrated within architecture and take advantage of peoples' natural movement within space. I developed an example of such AR application for museums with three specific interaction types: Based on Distance or proximity to objects, Orientation facing objects, and head angle. I evaluated this design through two consecutive user studies. First, I conducted a usability study with 11 general users asking the question of how usable and intuitive the different proposed interaction techniques are. Second, I conducted a focus group study with museum curators to understand the usefulness of such proposal for the real case of a museum. These studies resulted in important findings. I first categorize these findings based on the different spatial interactions:

- Distance: Users unanimously found the distance-based interaction easily and with minimal struggle. Domain experts also thought this interaction technique was very intuitive and suitable for the case of museums. I believe that the proximity/distance based interaction, as explored by other works Edward Hall [7] can be the primary way of integrating information in architectural spaces. These findings, to some extent, support this idea. However, more studies with direct comparisons to other techniques are needed to more clearly understand the benefits of this interaction technique.
- Orientation: Out of the 11 users who participated in the study, 6 users found it is easy to receive information from the orientation-based interaction. However, 4 users thought it was not as intuitive as distance and it was not as intuitive. Similarly,

domain experts found orientation to be useful, but they were not completely in agreement. One suggestion was to replace this interaction technique with the more standard gesture-based interaction found in mobile devices.

These findings suggest that to better take advantage of the spatiality of the orientation, there needs to be more studies involved. I suggest two possible research paths for future works. First, to modify the mapping of orientation to develop a relationship with the information presented in each stage of distance. This way, I hypothesize that users would more easily understand the relationship in more convenient way. Even though orientation-based interaction shows a lot of promise, for such interaction to be useful, we need more thorough studies and future explorations and studies.

- Head Angle: Out of the three proposed interaction types, head angle proved to be the most challenging one for users. Only two users discovered this interaction, one of them thought it is the toughest one. Domain expert did not like it as an interaction. Overall, one possible reason for this lack of discoverability might be the fact that our design neglected to include a signifier for this affordance of our system. This was due to our wrong assumption that this interaction would be completely intuitive as it only relates to users' own bodies. In the future, more work needs to be done to rethink the Head Angle interaction. Some future work includes to include signifiers and re-evaluate the interaction type. Moreover, this interaction is mostly suitable for head mounted displays. One of the other interesting findings of this study, was the inclination of domain experts towards smart phone

Augmented Reality. This seems to be a logical design solution for museums. However, the head angle interaction does not fit well with smart phone applications. The other question that I aimed to answer through my user studies was to understand whether users will use AR to explore large amounts of information about objects in museums. Figures 27 and 28 show aggregate maps of all of 11 users' movements and also their stop locations. These maps show that users interact and explore the information within the system in all categories and types.

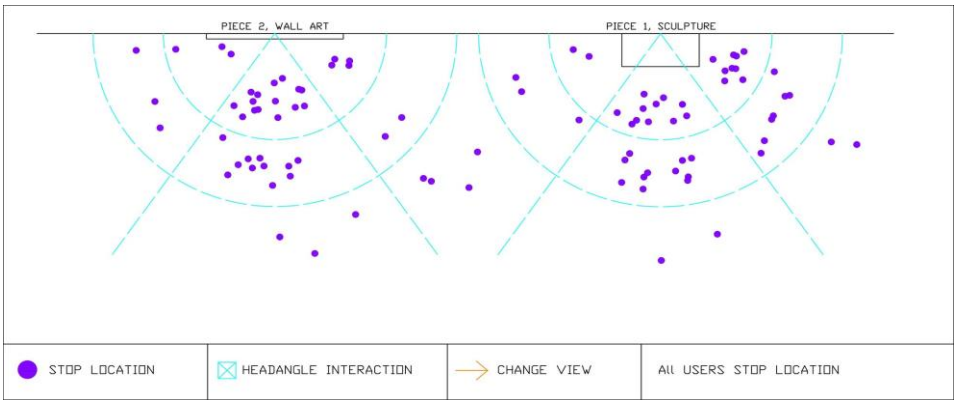


Figure 27: All users movement's map

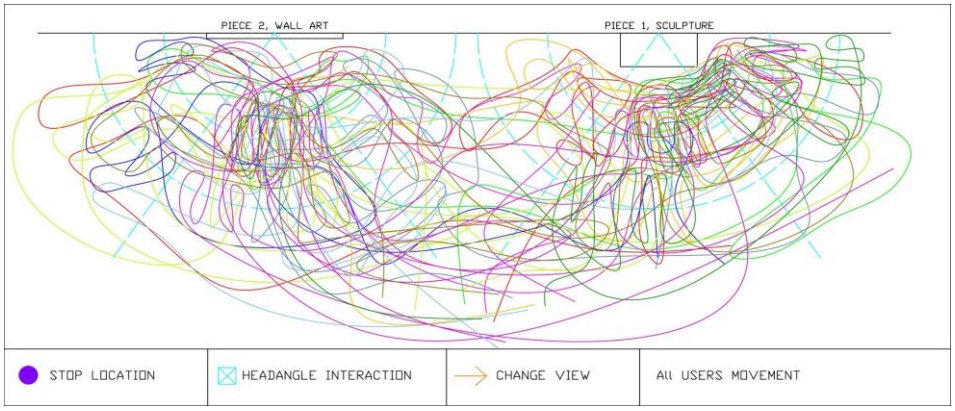


Figure 28: All users stop's map

CHAPTER 5: CONCLUSION

The user studies conducted in my research suggest that with some minor modification, AR can be a great tool to embed large amounts of more in-depth information and backgrounds in a way not previously possible through physical signage and other digital solutions such as Audio Guides since these solutions are not easily updatable and not personalized. One of the natural continuations of this work is to develop a more complete prototype using a smart-phone device and conduct more in depth users studies. Several modifications that can be done in the design process of the system:

Adding the direct interaction to the system. It can be so useful in different direction. Firstly, this will add the ability to filter through the available options and personalized information based on user's preference. This can potentially replace the need for the orientation interaction. Users can select the category of information by direct interaction then start spatial interaction by moving closer and further for receiving more detailed information. With implementing either options it need be deployed in a place such the Bechtler Museum, and another usability study should be done to further test these ideas.

By adding the direct interaction to the system, it would be great to test the system with both direct and spatial interaction to see how users interact with both system and what is the advantages and drawbacks of each one.

For Head Angle, there are two options. It can be used by adding a signifier inform user about the availability of this interaction, it needs to be tested again through a usability study to see how it works. Also, it can completely be removed and replace by another interaction. This interaction can be a direct gesture interaction, by adding the more button user can toggle the information and read another available information.

Overall, this thesis was an exploration into extremely complex questions. How can we create interactive spatial interfaces through which information can be naturally embedded. This work should be taken as a starting point for many future architectural and interaction design research and experiments where these questions are explored with more in-depth experiments. The change in the amount of information calls for a need for architecture infused with information. This thesis, showed that Augmented Reality and spatial interactions can be a very important solution for the future of architecture and information.

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APPENDIX A: CONSENT FORM

School of Architecture

9201 University City Boulevard, Charlotte, NC 28223-0001

Consent to Participate in a Research Study

Title of the Project: Testing Differently Augmented Reality Interactions

Principal Investigator: Seyedalireza Fatemi, student in a dual master program

Faculty advisor: Dr. Eric Sauda, Professor of architecture

Co-investigators: Dr. Isaac Cho and Alireza Karduni

You are invited to participate in a research study. Participation is voluntary. The information provided is to help you decide whether or not to participate. If you have any questions, please ask.

Important Information You Need to Know

· The purpose of this study is to study is to evaluate the usefulness of an interactive way of communication through the Microsoft Hololens, an augmented reality tool.

· You'll take part in three (3) phases lasting no more than two (2) hours. Phase 1 is a short training on how to use Hololens. Phase 2 is your using the Hololens and recording the point of view camera as you interact with objects in a space. Phase 3 includes asking you questions about your interaction and completing a short, 20-question questionnaire.

· There is no expected risk to taking part in this study. You may feel a little awkward wearing the head-mounted Hololens display but there are no known problems

resulting from wearing the device and it can be easily removed. This research may help us learn about how we can interact with real and virtual objects at the same time.

· Please read this form and ask any questions you may have before you decide whether to participate in this research study.

Why are we doing this study?

The purpose of this study is to evaluate the usefulness of an interactive way of communication through an augmented reality tool. Our tool is a head mounted display called Microsoft Hololens. Microsoft Hololens is a device that you will wear like eyeglasses that allows us to overlay virtual information into the real world.

Why are you being asked to be in this research study.

You are asked to be in this study because you are age 18 and older, and are able to read and write in English.

What will happen if I take part in this study?

The study takes place in three phases and the whole duration will not be more than two hours.

Phase 1 includes a brief training on how Hololens can be used. A member of the research team will train you and give you an introduction about the experiment and how to use Microsoft HoloLens.

Phase 2 involves the main part of study. At this stage, you will see a real object, a sculpture, through the Hololens. You do not have any interaction with the real object. You will start interacting with information *about* and related to the sculpture. We will ask you to use the Hololens to explore information related to the sculpture and to interact with this information using various interaction techniques such as your movements or using a

clicker. This information will be added to the real environment. You will explore the information-based on the training we provide. We will also video record your point of view using the Hololens. The HoloLens camera captures only what you see and no image of you will be recorded.

In phase 3, we will ask to answer some questions based on the interaction that you have in the space, it is a short questionnaire consist of less than 20 questions.

What benefits might I experience?

You will not benefit directly from being in this study. Others might benefit because this study is to help us make progress in developing a new way to help having more interaction with objects and receiving more information. The results will be submitted in academic journals or conferences.

What risks might I experience?

Because we are using Microsoft Hololens which is an off-the-shelf head-mounted display, you might feel some discomfort. However, there hasn't been any reports on significant problems with the device and the device has been thoroughly tested by many different researchers. At any moment, if you feel any discomfort, you can easily remove the Hololens and stop the interactions.

How will my information be protected?

The research team will make every effort to protect your privacy. All of your responses to the questionnaire will be kept confidential. Your name will not be retained in our notes, nor will we record any information that might be linked to you, such as a physical description. The videos will be linked to your consent forms with assigned ids and will not include your names. They will be destroyed after the completion of the research. Other

people with approval from the Investigator, may need to see the information we collect about you. Including people who work for UNC Charlotte and other agencies as required by law or allowed by federal regulations. When the results of this study are published, participants will not be referred to by names or any identifiable information. Only the feedback from your experience and the process will be recorded and published.

How will my information be used after the study is over?

After this study is complete, data may be shared with other researchers for use in other studies or as may be needed as part of publishing our results. Data we share will NOT include information that could identify you.

What are my rights if I take part in this study?

It is up to you to decide to be in this research study. Participating in this study is voluntary. Even if you decide to be part of the study now, you may change your mind and stop at any time. You do not have to answer any questions you do not want to answer.

Who can answer my questions about this study and my rights as a participant?

For questions about this research, you may Professor Eric Sauda (704-687-0124, ericsauda@uncc.edu) or Professor Issac Cho (icho1@uncc.edu). If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Office of Research Compliance at 704-687-1871 or uncc-irb@uncc.edu.

Consent to Participate

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. You will receive a copy of this

document for your records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above. I understand what the study is about and my questions so far have been answered. I agree to take part in this study.

_ _____

Name (PRINT)

_____

Signature Date

_____

Name & Signature of person obtaining consent Date

APPENDIX B: POST QUESTIONNAIRE QUESTIONS

Augmented Reality in Museum

Thank for testing our Augmented Reality system for Art!

1. What did you discover about how the system responded to your position relative to the piece of art? please list all the examples you noticed.

please comment on the following aspects of the system:

2. What influence did your Proximity to the piece of Art have on the information displayed?

3. How easy was it to discover Proximity as a part of the system?

4. What influence did your Orientation to the piece of Art have on the information displayed?

5. How easy was it to discover Orientation as a part of the system?

6. What influence did your Head-Angle to the piece of Art have on the information displayed?

7. How easy was it to discover Head-Angle as a part of the system?

Compare this system to the existing method of written information displayed on the wall near the piece of Art.

8. What advantages do you think this system offers?

9. What drawbacks are there to the system?

APPENDIX C: TRANSCRIPTS OF THE USER STUDY

User #1: I cannot see the third category. Where is the artist part? Oh it is so close to here. I can see the artist from here. The artist is for this one? “asking Q”. now I am seeing the artist for this one. The only problem that I have, you need to get too close to the wall and when I am close and I want to step back I need to look around. It is just the radius of interaction, I guess.

User #2: I am getting close to the object and I can see more details, I can see some images of the other works of the artist I think. I am getting close I am reading the text. I am getting the other side of the object, I just now understood different side of the object give different information. I am going toward the other object, I am getting further to see other information. Getting closer. Information about the artist. I am seeing the other object from here and I am seeing the information that I haven’t seen before. I don’t know why is it giving the information about Polad. Ok.

User #3: I can't read the text very well. The text now become clear. It is a little bit noisy the text is noisy. In order to read the text I need to change my head up and down. The little key map at the left help me to a kind of guide me to move around the object. I just found if I go kind of close to the object I can read the text much better in terms of the clarity.

User #4: I am beginning to read the text. So I just figured out when I move I can see my position on the screen on top left. It is blue and now it is read, And I don’t know how it is different. When I just went a little bit future the text changed. The text is a little hard for me to read. Maybe it is related to the lens not the system. When I keeping my head up the texts somehow moving, but when I bend my head it become fixed. So I am changing

my position to the right object, and still the same when I bring my head up the text moving, maybe it is related to the lens. I am changing my position again to get different information, but it is not changing the information is rotating though. I am using different gesture to see if they are working, but apparently it does not effect. I want to go to left, but I need to be careful to do not crushing any object. If I want to keep going to the position that I want maybe I crush the other object in the museum.

User #5: So I think I should move around, oh it rotates with me. I can see photo! Oh, ok I guess this style and I am in tab style right now. And if I want to go back to the object I probably, yes. So if I rotate I can see the different information. I was right. This is the artist, object, information about the object and style. Interesting. Ok, so I am seeing different photos from the previous one, I am not sure if they depend on my location or it depends on, yes it depends on how far I am from the object. The scale changed. I think I can work with it right now. It depends on the location and it depends on how far I am from the object. And I am getting different information when I am getting closer to the object. Lets try with other object. And I guess the default, I am not sure the first thing that I saw which was the blue tab. Now I am seeing again the style that related to the designer. Which I saw the similar one, but now I am moving further and the other one gives other style information. Something that I wish I could have was, because I usually have glasses and I wish I can zoom on the information for another object over there. I know that when I go closer I can read the information. I getting more info from this one, and the similar layout over here. So, lets see if I can see for both of them. Oh interesting, so if for example if I am walking down this path I can see multiple information for different objects. And I ca change based on the location what I can see.

User #6: I don’t understand what I can do with the artist, object and style. What is the relationship between down and up, aha ok ok! Can I chose any of them?! Text is kind of blurry for me. When I move, it is difficult to read them. I need to just stay in one place and, but even when I stay, it is kind of blurry. I cannot read them very well. The quality of the text when I move near to the object is much better that when I move further.

User #7: It is a little hard to see. It is move around. I can see the blue and green, but I cannot see the red one. It is hard to go to red. I do not get to red very hard. I cannot read everything on the red color, actually I can read but the position is so bad for reading. The position for another object is weird too, it is not comfortable.

User#8: I see it pops up and it tells me about the artifact and artist. This is matter where am I? see here, somewhere have a I don’t know I am try to , I see the images where I am future the abstract art and I in front of the art. I woo it is cool, see the different images like these. So this is the object here, and then here , I am still try to. Yeah I see clearly here where is the object, back here now this middle can be. Yeah this is pretty clear and I can read what is the object about. For this object here, the one thing that I can see it but sometimes cut off a little bit. I don’t know!

User #9: I can see the object. What is the small graph on the left side of the panel? I can see the semicircle holograph. Ok , ok. It feels like the panel is always in front of you wherever you are going. Like it is perpendicular to the wall and my eyes. It is always in front of you. And some thing, when you switch from the first, from this model to the picture the panel just switched. Ok and the picture several times changed as times. And it seems to me that the picture changed by changing my head. When your head is looking upward you can see different images than when you are looking downward. You can shift them by

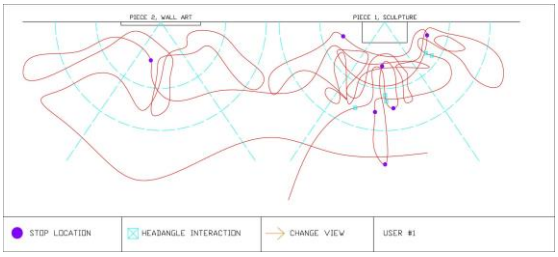
moving your head. Oh, so when you are in a different location from the artifacts, it can generate different type information about the object that you are looking to. Oh, artist, oh, so each part of the semicircle has the different typology which shift from the artist, the object

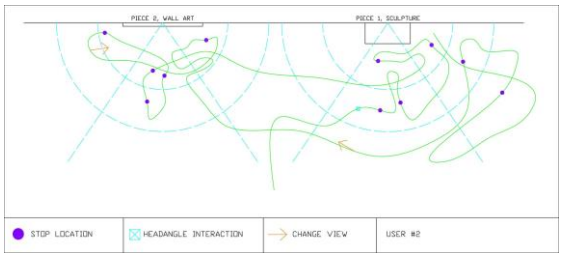
User #10: I can read part of it, lets see what happened if I go closer. So it divided to three parts. Based on the, so this one is just have two sides only. Let me try. Ok . I got the dimension, the general dimension. How about artist, do we get anything about the artist far away? Ok, we get. Ok, so the information is, the closer you the more detail you get about the part that you are being the artist or object. That is really interesting. Lets try the other one. And now I still, oh ok. The text is a little bit blurry. And star shifting. Oh this one has the third one. So, two of them has the three parts? Ok the style, oh I think it is a little bit of limitation. I should be aware to do not hit anything else. Ok. Conceptual artist. Make sure to do not hit, oh woo wait! I did not notice that the symbol on the floor! Artist, object and style. So, lets checkout the style on this one. I think the last one is getting a little bit close to the piece, might be a little bit further, people may hit the sculpture. I can see the floor, also the same thing with the artist, probably it is because of the layout, but it is getting a little bit closer, but the information can be read pretty easily. The only fact that I struggling a little bit with it is the limitation of the screen, that I actually notice about the floor after a while because I can see a part of it.

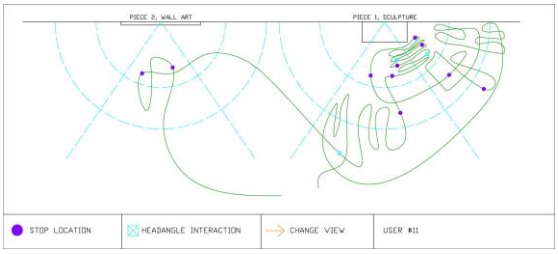
User #11: So the text just changed, but it kind of hard to read. It is like keeping go through, and as I like get up to it, it is a lot easier to read. So, I guess as I get closer it changes but still glitchy effect I guess. The text changes as my head turned. Should I go to the other one now? The text over here seems like further away from the actual object over

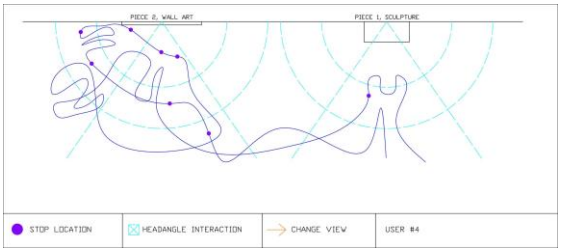
there. When I turned my head the text changes and show the other stuff. Oh it is just pretty cool. S, I guess when I walk around it changes. Actual angle changes and text changes based on it. And the panel is faces toward to me all the time, which is good. So further I get the text becomes bigger which is good, but still is hard to read because of the cancelation.

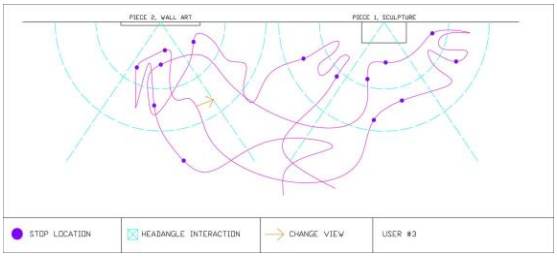
APPENDIX D: USER'S MOVEMENTS MAPS

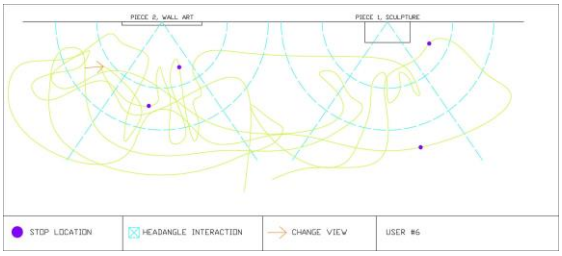


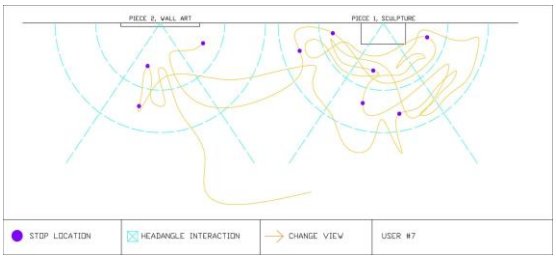


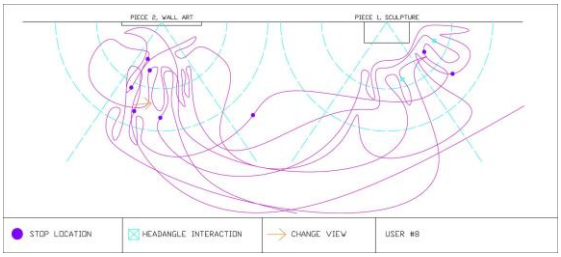


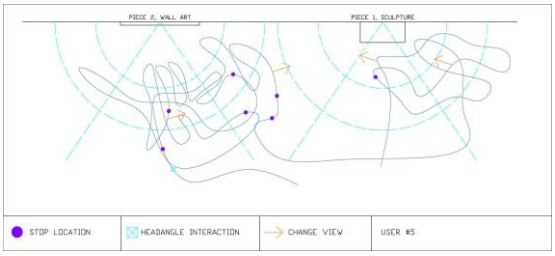


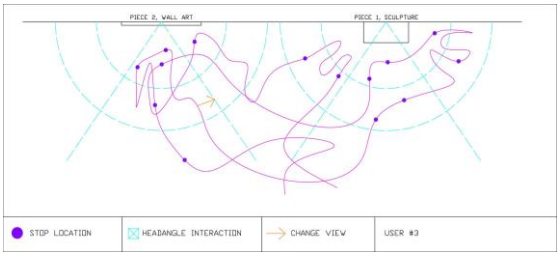












APPENDIX E: ALL USERS ANSWERS TO THE POST QUESTIONNAIRES

Answers to the question 1:

User #1: I understood different info presented to me through the device based on my facing toward the object. Depending on my position and distance from the object various info presented to me. In addition guide diagram projected on the bottom of object was helpful for understanding the possible interaction.

User #2: I understood how the logic of position and information works a bit late in the process, not in the beginning. The map diagram on the side helped a lot. I think that diagram needs to be more visible and maybe a point can be added showing the position of user on it.

User #3: The system is worked based on my position toward the artifact such as rotation and distance

User #4: The system is responding in three different sections (Artist, Object and style) based on my position on a semi-circle which is divided into three sections. As i'm getting closer or further to the object the information is changed in the same section.

User #5: I realized that I will get different information about the object that I am looking at. I wasn't sure at first but the semi-circle sign was helpful for clarifying that there are different stages and levels of information provided.

User #6: I had a great experience since it seems much easier to see the specification of the piece of art with the new technology. It represents perfectly the specification of the piece of arts from all directions and distances. It was difficult to read the text when i was at the third circle and specially when I was moving.

User #7: the type and amount of information revealed depend on proximity and orientation relative to the art.

User #8: The system was very clear on information for both art pieces on left and right; however right side information appeared to be cut off just a little.

User #9: When you are facing the art work in different angles, you can see the panel is always facing towards you. And when you are at the different distance from it you can see the information is changing as well as the font size. When you are looking upwards and downwards from one position you can see different types of information.

User #10: Depending on the position I could discover three main types of information, about the "style", "object" and "author" of the piece being displayed.

User #11: As I got closer to the art different text boxes popped up, and the same thing happened as I moved around the art. Different images also popped up, giving more background to the style of the art.

Answers to the question 2:

User #1: based on the distance information projected on the side of object changed.

User #2: The information became more detailed and more in length as I got closer.

User #3: The size of text is changed and new information appeared.

User #4:The proximity was changing the information in the same section of subject.

User #5: The closer I was getting the more detailed information became for each category.

User #6: Since I could see the information far back from the piece of arts, It was easy to read the text from a distance to the object. The only problem i face was that I was not able to read the text very well when I was moving at the third circle.

User #7: more information revealed as i got closer

User #8: Proximity provided additional background information about each piece of art which is very helpful

User #9: The font size changes and the typology of information changes.

User #10: The closer one gets to the piece the higher level of detail information is showed. Going from general to specific (far to close).

User #11: As I moved closer the text changed and got smaller. As I moved around the art, the category of the text changed from object, to style, etc.

Answers to the question 3:

User #1: It was easy and instant.

User #2: The proximity was easy to discover, but the differences between angles of looking at the object were less intuitive.

User #3: That was easy to understand because the key map helps to make my mind and facilitate the process

User #4: It was pretty easy

User #5: It was very easy. At first, when I realized that I am seeing a different information, I was wondering why this is happening. Then I looked into the semi-circle sign beside the information panel and I realized that I am in a different depth. Then I realized that my proximity is affecting the information that I am seeing beside the object.

User #6: It was straightforward to discover that as the proximity illustrated at the top left side so I could distinguish my distance to the object.

User #7: yes, but i also knew about it before starting the interaction

User #8: It is easy to understand and use proximity; however the art piece on right side was some what hard to read until you re position the body

User #9: Quite easy it doesn't require too much distance to get the change

User #10: It's repetitively simple, very intuitive.

User #11: At first I could tell the text was changing but I didn't really figure out how my proximity affected it until I was about halfway through the study. At first I thought it was how I was holding my head, but then I realized the map on the upper left side of the image, as well as the map on the ground.

Answers to the question 4:

User #1: different information types were presented

User #2: Changes of orientation changed the type of information. I did not notice the similarity of

categories between both items until the end of experiment.

User #3: the content is changed as I walked around objects, the new information about artists and objects appeared.

User #4: The orientation was changing the information subject. (Artist, Object, Style)

User #5: I was able to change the type (category) of information that I was seeing.

User #6: I feel no difference between the information displayed from different orientation.

User #7: the type of information changed; artist, object, style

User #8: My movement change each additional information about the pieces of art

User #9: It changes from Artists to Object and to styles.

User #10: According to the orientation you could see three main subjects about the piece.

User #11: As I moved around the piece of art the category of text shown changed from artist information, object, and style.

Answers to the question 5:

User #1: it was a bit tricky to find out about the information on the red segment because I had to get close to the wall in order to info appear.

User #2: It was less intuitive than the distance.

User #3: that was easy to understand

User #4: Easy

User #5: It was very clear because the there were different colors for the sections and they had labels corresponding to the title of the panel close to object. If I want to compare it with the proximity, it was easier to discover.

User #6: It was easy to discover it.

User #7: wasn't as easy as proximity, realized it after it was mentioned out

User #8: When using the system it was easy to understand the concept of the device

User #9: When you are near the art work it's easy. When you are far away from the art work, you have to travel a long distance in order to discover the orientation changes.

User #10: Orientation I think was the easiest thing to discover as the color changes are easily noticeable.

User #11: This took me longer to notice than it did the proximity. I didn't notice this different until I saw the map on the left portion of the image, as well as the map on the ground.

Answers to the question 6:

User #1: I didn't get it.

User #2: I did not notice that.

User #3: it worked like scroll bar on the windows page. the text and contents are extended

User #4: The text was not vivid at first and it became vivid by head angle. I haven't discovered anything less.

User #5: Changing the type of information.

User #6: I was not able to recognize any difference between displayed info and the head-angle.

User #7: only noticed the orientation guide after being told to look down

User #8: Did not get it

User #9: The information of style of the art work changes

User #10: As you moved your head up and down you cold discover additional information about the subject presented.

User #11: I didn't notice any influence on my head-angle. I thought the image stayed pretty steady.

Answers to the question 7:

User #1: Hard

User #2: Not easy.

User #3: that was easy.

User #4: I speculated that when I am looking at the three categories, the type of information was changing. After Alireza's explanation, I could change the categories with the the my head-angle but it wasn't very intuitive.

User #5: It was easy to discover.

User #6: not easy at all, only realized it after i was directed to look down for orientation info

User #7: Did not get it

User #8: When you don't understand the Head-Angle is part of the experience, you may feel like it is malfunctioning, but when you discover how it works, you will feel it pretty intriguing

User #9: The head angle was the toughest as it is the hardest one to notice.

User #10: Again, I didn't notice any influence with my head-angle, aside from maybe some glitches and pixilation in the text.

Answers to the question 8:

User #1: It is more inviting to read about object also it divides info into subjects that makes it easier to understand.

User #2: It is more effective in giving the information to the user, since it gets the user's attention. It also makes the items and the whole exhibition more dynamic and attractive.

User #3: it contextualized the artifact by providing good information about the artist, his relevant works and philosophy

User #4: It was interesting to interact with.

User #5: For a compact environment such as a museums where people might care about different types of information and displaying all the information is not feasible.

User #6: I really like applying this method of representation for displaying info in museum in comparison with common (written) method currently use for displaying information.

User #7: it makes it

User #8: Being able to engage with the information and photos more interactive way while in motion

User #9: It allows you to see more information and saves more space.

User #10: The system offers additional information that otherwise will not be exposed to the public watching the exhibition. Providing context and knowledge.

User #11: The displayed text in this system definitely kept me at each piece longer. Also, the different levels of text drew me in closer and got more specific. All the background information provided on the text of the style/artist made me appreciate the art piece more.

Answers to the question 9:

User #1: It was hard to orient in the gallery environment because for information to appear I had to move around while I had to be cautious about not hitting other objects in gallery.

User #2: The diagram showing the user position needs to be more clear and bold.

User #3: The lens was heavy

User #4: I wear glasses and even with the change of scale in the system it was hard to read the further object's information. It was good if I could scale the information with zooming or a hand gesture.

User #5: The weight of the glass. The lack of visual information.

User #6: I preferred there was a possibility to interact with the piece of art and be able to choose some info or go through some pictures or videos related to the piece of art.

User #7: HoloLens was very uncomfortable, and since you have to move around to explore how to change the type and amount of information it can be problematic in presence of other viewer or more crowded space.

User #8: Some positions have better imagery than others

User #9: Not friendly to people wear glasses.

User #10: The main drawback I can find is how people interact with these pieces, but how will they interact with each other and not bump into some of the art pieces or other people.

User #11: If I was in a room with a lot of people using the same system, I would probable bump into them a lot. I had to pay special attention to my surroundings, which made me some what paranoid the whole time.

Answers to the question 10:

User #1: Device is very interesting but it's weight gets disturbing after a while.

User #2: The music needs to be less distracting, unless the artist has requested it. The information could be more clear in text and color. The information shown from far away should be very short and in large and clear text.

User #3; The system provide great interactive experience. The only challenge was about reading. The information (text) is hard to read specially when the distance is not too close to the object. So this issue distract me few times.

User #4: I had to be cautious with moving according to the small space. I'm guessing you're planning to implement this system on a larger space.

User #5: I really liked the work and I believe it can be useful in many contexts. and I think it is very scalable.

User #6: It is a great breakthrough for displaying the info in places like museum. If it can integrated with some visual effects related to the piece of art it would be more informative.

User #7: adding a directory navigation might help so effects of orientation and proximity would be easier to realize

User #8: This system is very entertaining to use

User #9: Creative, promising, and full of potential.

User #10: I think the idea is excellent as it can provide additional information to the people visiting museums, information that unless you know it beforehand will not probably know it.

User #11: With the orientation aspect of the system, I sometimes had to stand very close to the wall and was actually in front of the surround art pieces. This would disturb other people in the room who were observing other art.

APPENDIX F: TRANSCRIPTS OF THE FOCUS GROUP STUDY

P1: we will give you demo for 10 to 15 minutes, thank you for your time, so the idea is to show the dynamic information to users in museum setting. Also users can see the information based on their preferences. The information is not presented just in a piece of paper, we can capture all information in an interactive way. We want to know the idea of curators and their thought about project to have more information in our research. Ultimately, based on users preferences we can have better design. Basically, we want to provide information and what is the issue in this way. So basically we want to know this is the thing that you guys like it?

P2: it is a cool idea to present more information.

P1: basically this is one of the main issue that want to address, there is a limited space and we want to show more information. What should we do? Are you guys familiar with different technology that can solve the problem? Voice recorder or something?

P3; Oh yes, audio guys.

P2: several apps in different museums.

P1: Do you guys like it?

P3: we actually, we just starting, and hopefully finger crossed by Friday this week we have the new audio guy by the platform called guy ID. and it is and an audio guy. We going to record content. There is going to be a little grey block on the wall that triggered that you can interact with it and hit the play button, there is a speaker and headset that you can listen to your phone to the prerecorded information. There is apps that are often can paired with this to the audio guys and things also we will pay an extra premium each month to app become available to you. Is often branded or it is there zero experienced unless you

pay money to create an appropriate app for you. you are just hosted on the your website and ask for an app.

P1: so there is an app

P2: so be realistic with the audio guys you can not go the specific part. You need to listen to the entire part, so it not interactive that when you are looking for the specific information you can find that part.

P4: so when you arrive to the location it start playing

P2: yes exactly, you need to listen top the entire museum.

P4: I did the same thing.

P3: I would say that, they usually have number on their device, you can listen to the different thing.

P4: how dense we should go for the information. We can keep getting more and more information. But, probably for your point of view, for some pieces there are some books about them. But we need to know your advice about how dense we need to put the information.

Demo session:

P1: we are trying to combine the technology with the way that people naturally move. Because in museum people moves around. Trying to do that. We have two devices. As you interacting tell us what id your thought, because we are recording and we are trying to know what is the experts idea about our device, these are the parts that they like it or these are the parts that they do not like it.

P5; As you can see in my laptop screen, when you look at the ground you can see the, actually based on your location you can see the different information. So, you can see

the three different categories over there. On the left side you can see the information about the artist, and in front of the object you can see the information about this object, and on the green color and right side you can see the information about the style of this object. So, now I am far away from the object and I can see the high level information.

P2: it is hard to see on the laptop. Can you?

P4: let them to try

P2: I love the images that are available in there. So, object, artist, style. How I can change them?

Danilo: you physically move and change them.

P4: just keep moving to see until you see the different information.

P2: so I cannot see the information about the artist.

P5: you need to move closer to wall, here probably you can see it.

P2: oh yes, here I can see.

P1: so, it is a problem, but this is a prototype of the system.

P1: TESTING THE ANDROID SYSTEM

P1: we got the information from, P3, which was great. Also we search and found some information in Wikipedia.

P22: So, I am wondering if we have in a gallery so many pieces and I want to switch from one object to another. When you look around you can see the different information in front of you! What is it look like? The sensor can understand where are you?

P4: well, each of the piece has something the same as this QR code, that when you look at it you can see the information.

Caty suggesting that instead of moving back and forth, people have the ability to select on the phone screen and see the more information.

P4: So, we can do something, when user comes we can give them an overview. When you move closer, you can focus more on something. Also, it can give another information, about the other galleries, that there is similar object in another gallery.

P4: it is interesting something about the cell phone you can naturally interact, and whenever you need to see the object just toggle. This is something that might be true not necessary true.

P2: would you access to the story of presenting information? That one user looks at the specific objects.

P4: absolutely, we can track where have you been and which pictures you looked at. This is some thing that happened in museum today, they are tell you what are the similar objects. If you are interested in specific style, it will tell you let me show where you can find more.

P1: we will hope that in future we will have the voice introduction for the system.

P4: another thing that we want to know, what type of information and which categories are you interested to see.

P2: finding a way to show the relationship between the different objects in a museum setting. I like the distance better than the rotation. It would be great that you can combine the distance with the ability to click, for instance when I am standing here I can select the category and when I move closer I can see more information.

P3: and it would be great, because I don’t know that it's just me or, I see an object from the distance and I am not trying to move closer.

P2: I agree. It will encourage people to do that and move closer.

P1: we have this idea, and it was our initial goal, to make a comparison between the direct interaction with indirect, spatial interaction. So what is your idea about the spatial interaction?

P2: I really like the supplement of images, and if you could guide us to the artist background life images.

P4: supplemental slide show of the artist’s other jobs would be interesting. Research a bank of images produced regularly.

P1: also the good thing about the spatial interaction, we can add 3d images to it.

P2: that is really interesting.

P1: Basically our idea was to have the dynamic interaction in a physical spaces. And we can update it very easily with this platform.

P4: also, you can ask expert to add to it. For instance about the Sol Lewitt, if you know anything about him, go ahead and add it to the content. And, it can go the website and automatically the content can be available.

P2: so how people can select the part of the information that they are really interested in it? They need to say like it?

P4: we try to avoid to many inputs. Where they go to the museum. Providing example about the Koolhaas project. Have different galleries based on the period of time and location of the piece of arts.

P3: having a little background and history information is really really helpful. The context that has this piece of art inside of itself. The process it takes for the fabrication.

P2: it depend, for some piece of art, the process that it takes. But, for the historical pieces, the context and background, the wars and the location that surrounded this piece of art.

P4: we want so persistency in presenting information.

P4: do you see any specific problem with it?

P2: the technology is not necessarily intuitive, you cannot find where is the exact information located. How to use it. It does not have any instruction.

P3: if the goal is to train the user, may be get rid of the zine and simplify the information. The left side is artist, the missile part about object.