REACTIVE URBAN SPACE

DESIGNING SEMATIC WAYFINDING EXPERIENCE WITH SPATIAL AUGMENTATION

by NURIE JEONG

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ABSTRACT

Finding one's way in unfamiliar urban centers can be overwhelming for pedestrians given the quantity of information available and uncertainty of decisions. Moving between multiple different types of information and navigating at the same time causes cognitive overload. On top of that, users also experience safety hazard while walking through an unsafe neighborhood or road with no sidewalk as guided by their GPS. This is because most current map solutions focus mainly on navigation, moving from one place to another at the shortest distance. Wayfinding, on the other hand, can be defined as spatial problem solving, which requires the users to get various kinds of peripheral information including safety, unexpected delay, and so on. The ideal wayfinding experience should be able to reflect travelers' ability to achieve a specific destination by providing semantic information. This project, targeting pedestrians exploring in urban space, envisions the near future where the real space becomes the next web browser, powered by 3D model mapping, augmented reality technology and speech recognition. The illustrations will show how the urban explorers get semantic wayfinding information directly from the real space and buildings, supporting the ideal urban navigation experience.

INTRODUCTION

Wayfinding in an urban space is such a complicated task that requires both navigation skills and a good understanding of a target environment. Urban areas are surrounded by skyscrapers and obstacles, making it hard to foresee the distance and get oneself oriented quickly. Because of its tricky nature, it is difficult to reach to destination without delays or mistakes, especially if he/she is traveling in an unfamiliar city. Uncertainty is another wicked aspect of the wayfinding experience - even if the user successfully reaches their destination, there is no use if the place can no longer provide a service that he/she wants. In this case, the user would feel frustrated and spend extra time on investigating alternative options. That being said, once the user gets his/her own techniques for self-location, wayfinding becomes a lot easier. Eventually, this confidence will bring the user to the joy of urban adventure, which ultimately helps expand his/her experience and knowledge in a new city.

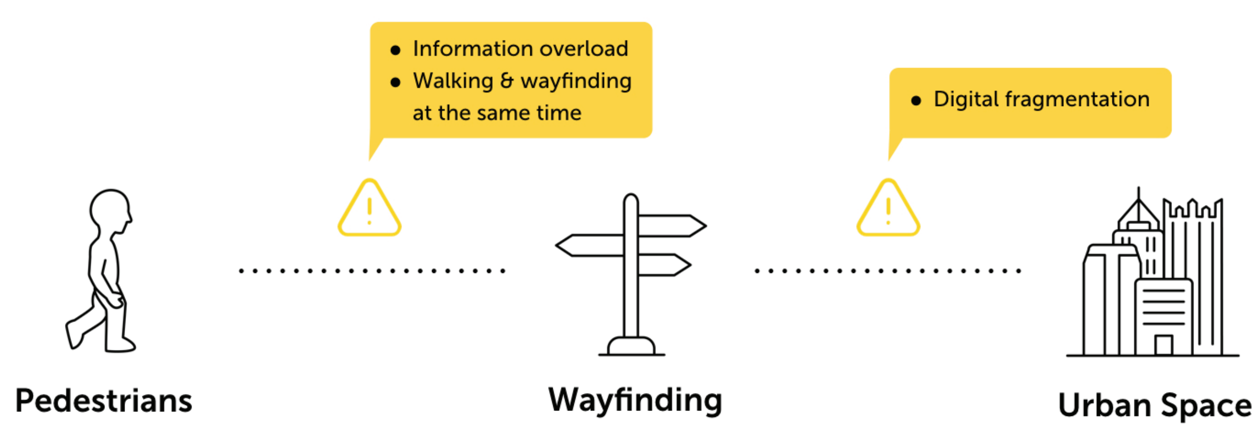
Thanks to the development of reality computing and artificial intelligence, it is getting easier to see and search information on a local area. Google I/O 2018 has recently announced more elaborated, the human-like voice assistant that can be combined with their Maps data, showing the impactful possibility of getting information directly from the real world, without Googling a keyword. [1] That being said, it is hard to say that these technologies shift the paradigm of our everyday life, as they haven't successfully presented long-term values to the users yet. Nevertheless, the recent showcases on emerging technologies inspire engineers and designers to delve into one important question - how might the new technologies care users in a better way?

Reactive Urban Space is started from the idea to design a solution that fosters user's confidence in urban adventure using the emerging technologies. A lot of people hesitate to travel a place they have never visited due to a mental and emotional burden of wayfinding. They also experience stress when trying to use public transportation they have never used before, worrying about missing their bus/train or getting on the wrong one. Consequently, this emotional stress creates a barrier in people's mind. If they can prevent themselves from delays and mistakes, their travel experience would be a lot easier and pleasant.

TARGET CONTEXT

Reactive Urban Space (RUS) aims to help pedestrians who try to find a way to reach their destination in an unfamiliar urban space. The goal of RUS is to solve two major problems involved in the target context; first, the pedestrians have mental overload while walking, navigating and searching local information at the same time. American Psychology Association has already pointed out that performing more than one task at a time have found that the mind and brain were not designed for heavy-duty multitasking, which eventually causes cognitive overload. [2] Second, the pedestrians experience digital fragmentation as information needed for wayfinding are scattered to different applications. Digital fragmentation causes the increase of interaction cost because the pedestrians should download all the applications they need and move between them to gather the information.

Based on the problems in the target space, I pulled a design question for designing RUS: *How can users expand their ability to explore and unfamiliar urban space and reduce information overload with new technology?*



PART I

EXPLORING URBAN SPACE

01

REFRAMING WAYFINDING

1.1. WHAT IS *WAYFINDING*?

Urban pedestrians often confront a various type of bottlenecks during their experience, but what exactly brings these pain points to them? To diagnose the design problem of urban wayfinding experience, I started from investigating literature on the concept of wayfinding.

The term Wayfinding is first introduced in 1960 by the American urban planner Kevin Lynch in his famous book The Image of the City, where he defined it as "a consistent use and organization of definite sensory cues from the external environment." [3] Lynch argued that well-designed urban environment improves the potential depth and intensity of human experience since the clear and vivid image of the environment and landmarks help the user to figure out the outline of their path. [3] His envision on wayfinding indicates that the activity originally focused on spatial cognition rather than finding the path.

In 1984, environmental psychologist Romedi Passini expanded the concept of wayfinding to include the use of signage and other graphics communication, visual clues in the built environment, audible communication and tactile elements, including provisions for special-needs users. [4] Passini argued that humans' perception of surrounding space and behavioral ability to reach a spatial destination defines one's wayfinding decision. [4]

In the late 1990s, the concept of wayfinding started embracing 'uncertainty' of its nature. Allen (1999) describes wayfinding as a purposeful movement to a specific destination that is distal and, thus cannot be perceived directly by the user. [5] He claimed that successful wayfinding is reflected in the user's ability to achieve a specific destination despite the uncertainty that exists [5] Allen's definition on wayfinding implies the concept of exploring - enabling travelers to enjoy discovering routes.

In summary, the definition of wayfinding has been continuously changing over the decades, and the target subject has been moved from urban environments to human's cognitive ability. The term was originally coined to stress the importance of urban planning, but nowadays it supports the concept of exploring empowered by location-based information.

1.2. NAVIGATION VS. WAYFINDING

It is common to mix up the term navigation and wayfinding, and indeed, they are somehow interchangeable as both indicate the movement from one place to another. However, there is a clear difference between navigation and wayfinding in a way that wayfinding activities require users' ability to make decisions to find their ideal route from the departure to the destination.

In their book, Hoffmann and Wellenhof defined navigation as the process of controlling the movement of a craft or vehicle from one place to another, including planning and recording process, which purely focus on trajectory determination and guidance. [6] This indicates two things; first, navigation is the process of finding an optimal route that can reach the destination within the shortest time. Second, navigation is an information process for the machine, not human-oriented activities.
On the other hand, wayfinding might not explicitly pursue trajectory determination depending on the user's willingness to explore the surrounding environment and their situated conditions. Arthur and Passini claimed that wayfinding is a framework of spatial problem solving and consists three interrelated processes - decision making and plan development, decision execution and information processing which requires environmental perception and cognition. [7]

Based on the literature, I made a diagram that shows the difference between navigation and wayfinding as figure 1.2. Figure 1.2 explains two main characteristics of wayfinding; first, it's the user who makes the final decision on how to move. The optimal path might vary depending on the purpose of the movement and external factors. Second, wayfinding requires a deep understanding of the environment and peripheral information so that the user can change the plan if necessary.

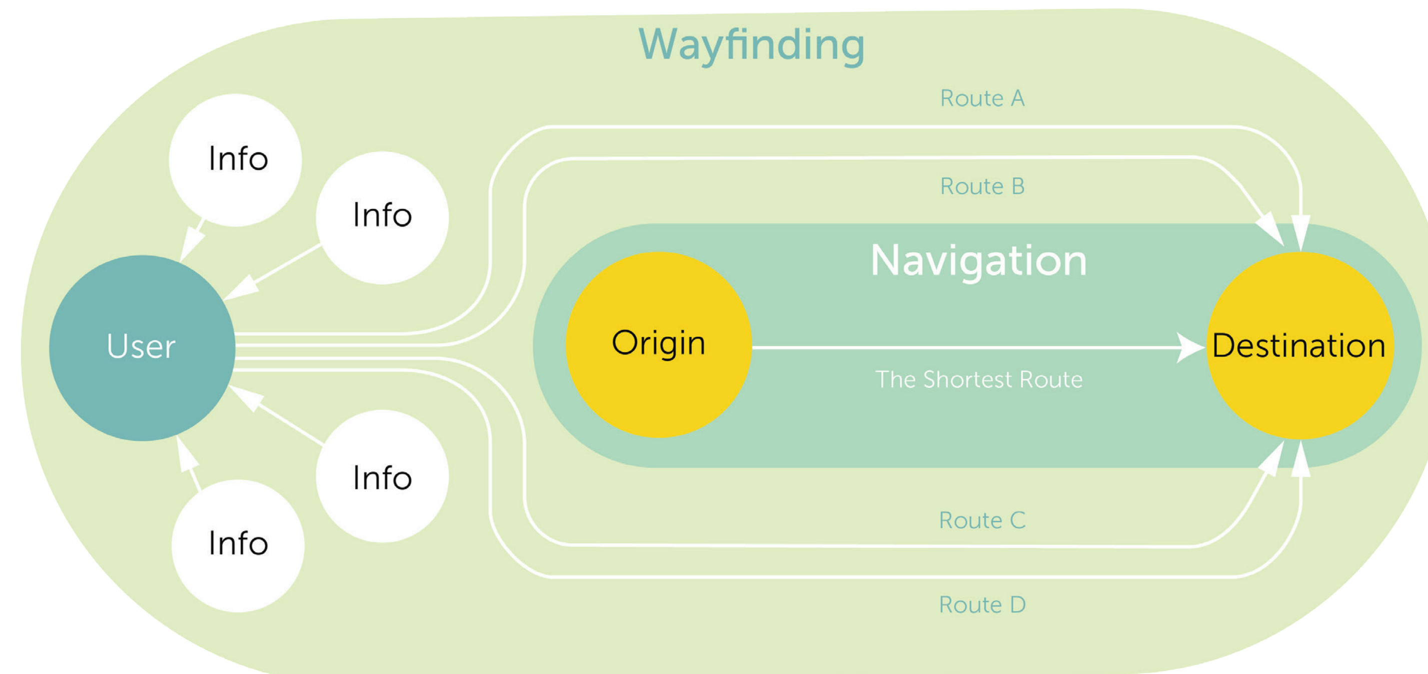


Figure 1.2. Navigation refers to the optimal (or the shortest) movement from origin to destination, whereas wayfinding means more for spatial problem solving that requires a user's ability to process information and make a decision to move

1.3. THE ONTOLOGY OF URBAN SPACE

The concept of wayfinding and the difference from navigation indicates the importance of information on surrounding environment and target destination. There are a couple of projects applying semantic mapping technique to wayfinding experience. Hochmair (2002) claimed that the ontology of the environment plays an important role for wayfinding, as the perception of the environment function as input for the decision making process. [8] In his dissertation, he analyzed the semantics of navigation information in Vienna International Airport to identify the what is in a specific domain in a general way. [8] Cosgun (2016) designed a navigation algorithm for robots to create maps that include various types of semantic information to allow the robot to have a richer representation of the environment.[9]

Referring to the previous semantic mapping examples, I reconstructed the information structure of an urban environment. (Figure 1.3) Branching out from Lynch's five elements of an urban space structure - Paths, Edges, Districts, Nodes, and Landmarks - dozens semantic information is embedded in the environment that can give a better understanding of the urban environment. Although these five elements are easy to be recognized by the user, the majority of their semantic information is abstract or unseen in the environment, causing a large amount of effort to search for.

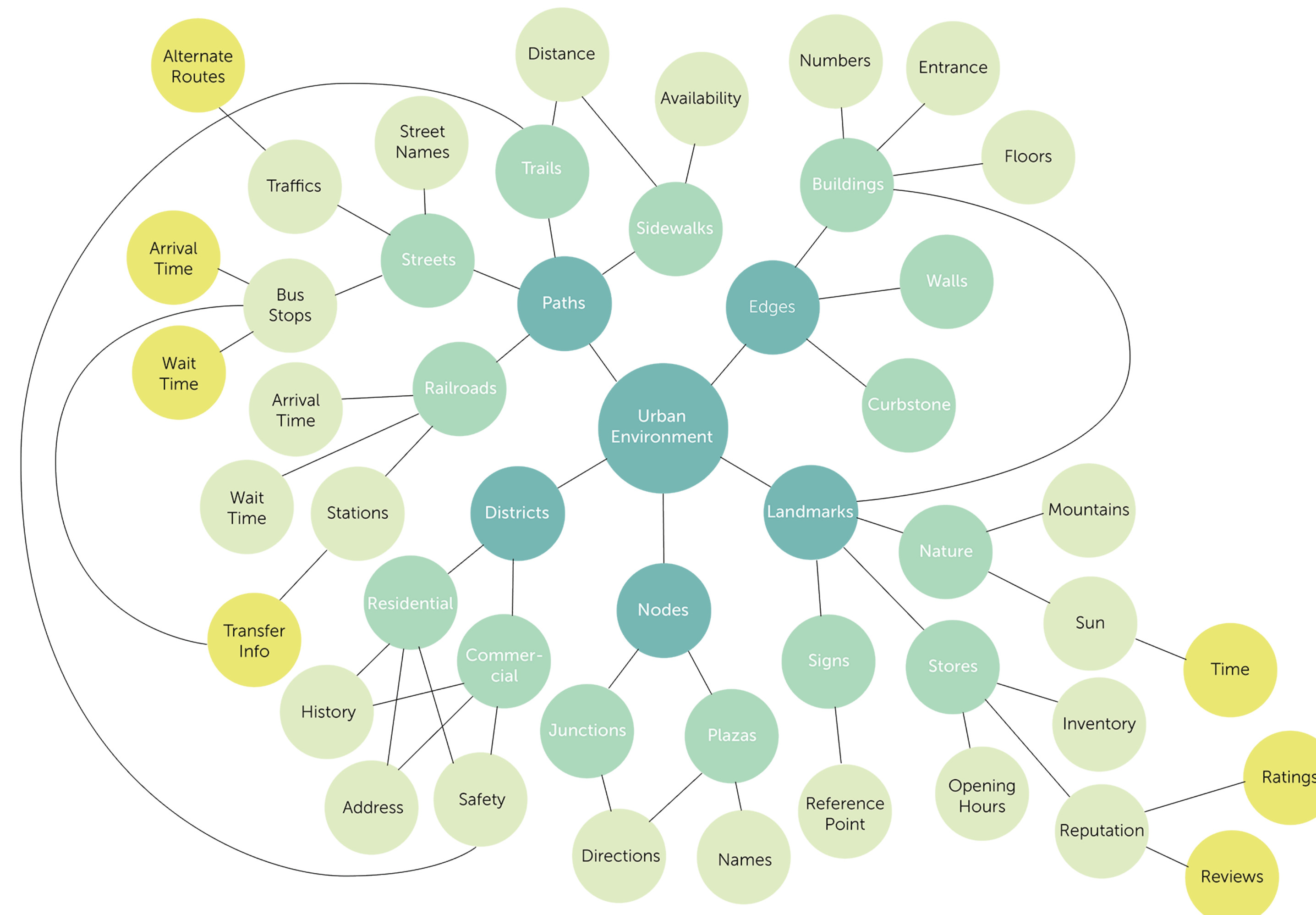


Figure 1.3. The semantic information mapping of an urban space

1.4. REFRAMING TO SEMANTIC WAYFINDING

In summary, wayfinding is a sophisticated activity that requires the user's ability to perceive urban space and make optimal decisions. The semantics of wayfinding indicates that user-friendly wayfinding experience should consider not only navigation information but also peripheral information to support urban exploration at full extent. Based on the literature review, I reframe the concept wayfinding from spatial problem-solving process to ***exploratory movement with the semantic information.*** Consequently, the urban space where the semantic information is fully provided will expand the user's experience and confidence to enjoy urban adventure despite its uncertainty.

02

UNDERSTANDING THE PROBLEM SPACE

2.1. ANALYZING MAPS SOLUTIONS

This chapter will focus on more practical approach by analyzing how and what kind of semantic information is provided through current maps applications and identify pain points in the wayfinding experience. I searched for a short navigation route on Google Maps and listed up all type of semantic information needed to move from Carnegie Mellon University to UPMC emergency care center. On the first page, the current map solutions provide a series of suggested combination of walk and public transit information including the number of bus/metro line, estimated arrival time and the total amount of time to reach to the destination.

While the map solutions are providing major semantic information on the two-dimensional map view, the user might feel the information gap when overlaying the map information in the three-dimensional perspective view. The first critical information lacking on the map view is inbound/outbound direction, which causes confusion in orientation. In the given map view, it is not easy to figure out the direction since the resolution of the road is not high enough to recognize it. While the driving navigation mode automatically rotates its view to head the drivers' direction, the pedestrians should get oriented by rotating themselves. The inbound/outbound direction information is especially important when taking public transit, since taking it on the wrong side will cause a huge amount of delay and frustration.

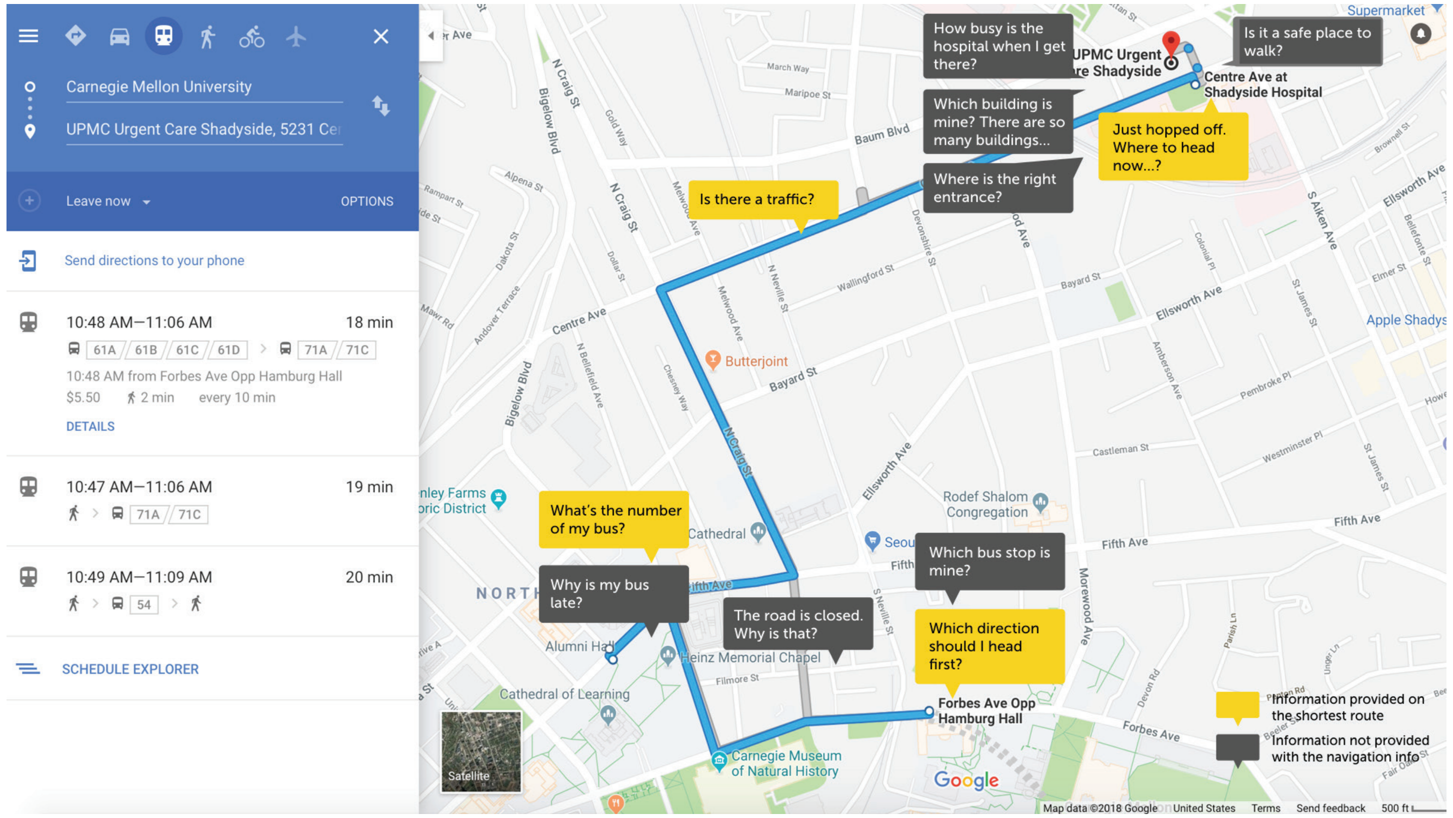


Figure 2.1 The list of information requires a navigation experience

On top of that, the default map view on screen is fixed to head north, while the users might head any directions in the real space. According to Lobben's study, this causes a mental overload as the users have to rotate the map shape in their mind to match their front view to the top side of the map. [10] This mental rotation process might take longer when there is no conspicuous reference or landmark nearby.

One another pain point in the current map view is that a lot of peripheral information not directly related to the navigation is missing or hidden. As seen in Figure 2.1, this navigation route does not include information about the safety of a place or sidewalk closure, which is very critical in walking navigation experience. To figure out those kinds of information, the user should visit the city authority websites or other location-based information applications, which requires a significant amount of interaction costs and cognitive overloads.

2.2. ANALYZING LOCATION BASED SERVICES

Along with the maps applications, the pedestrians also use other location-based services to gather further information about their surroundings and destinations. The most commonly searched types of information are 1) real-time transit (Transit, Citymapper), 2) local guide (Yelp, Tripadvisor) and 3) shared riding service (Uber, Lyft). These services support semantic information that the maps applications don't provide, but to make decisions, the users should move among all different applications.

Continuing from Figure 2.1, I extended the user scenario to find a restaurant near UPMC emergency care and reconstructed the user experience flow in wayfinding with captured application screens. As seen in Figure 2.2, the users might use three different applications and take at least four steps to complete one wayfinding task. This exercise indicates two design problems; first, the overall interaction of gathering semantic information is not seamless because it's spread all different applications. Second, if the target restaurant is not available due to unexpected closure, then the estimated interaction costs would be increased significantly.

Figure 2.2 also illustrates how the current urban environments are digitally fragmented by the type of semantic information. This causes a large amount of time taken for decision making and mental overload especially when walking and searching for the information at the same time. Figure 2.2 indicates the necessity of designing an integrated local information platform.

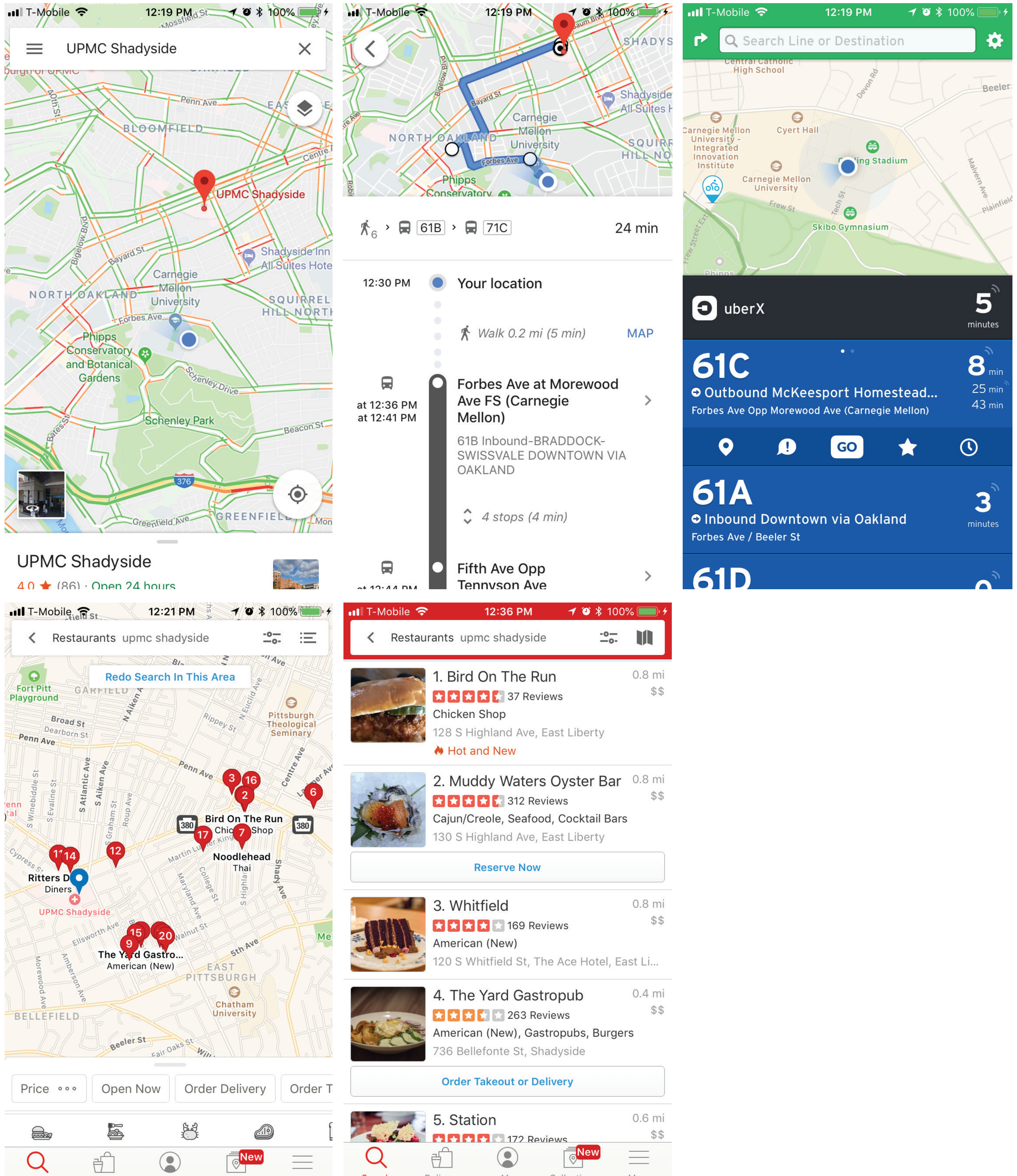


Figure 2.2 The user experience flow of wayfinding [11] [12] [13]

2.3. ANALYZING URBAN SPACES

Urban spaces, particularly the downtown areas, are often designed as grid plan in which streets run at right angles of each other. This type of structure makes the users feel hard to get oriented and verify their current direction because the shape of roads and blocks look identical in the map view. Figure 2.3.1 is the image of Manhattan area pulled from Google Maps. To figure out the current location, the users must need to know the name of the streets, avenues and the number of buildings. The nature of the grid plan might hinder the users' willingness to navigate without checking the map view because the identical shape of blocks and roads makes it hard to remember key reference points.

One another problem in the complex structure of the urban environment is the overlapping of multiple transits stops. As seen in Figure 2.3.2, since the multiple bus lines meet in downtown, it is quite common to see several bus stops located at the same block or interaction in downtown areas. Finding the right transit stop in densely built space is not an easy task even with the maps applications because skyscrapers or highways in surrounding interfere GPS signal, causing unstable fluctuation of the current location indicator.

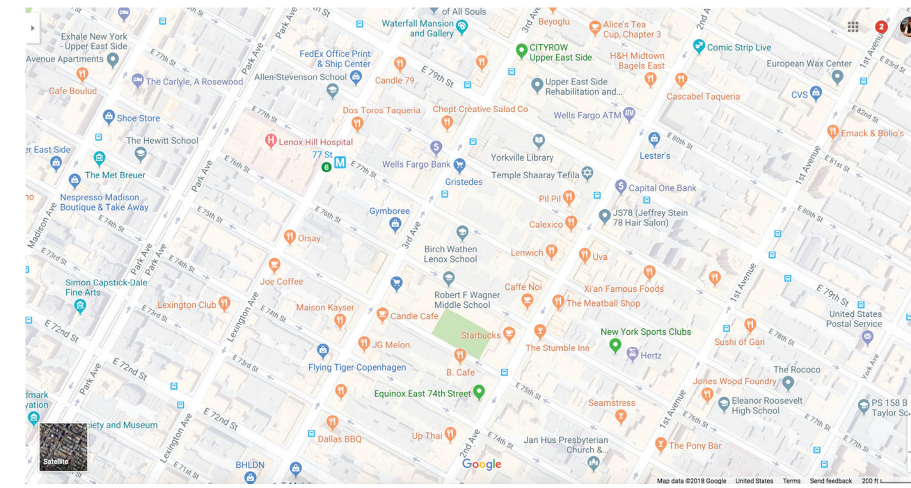


Figure 2.3.1 Manhattan is the most extreme case of the grid plan [14]

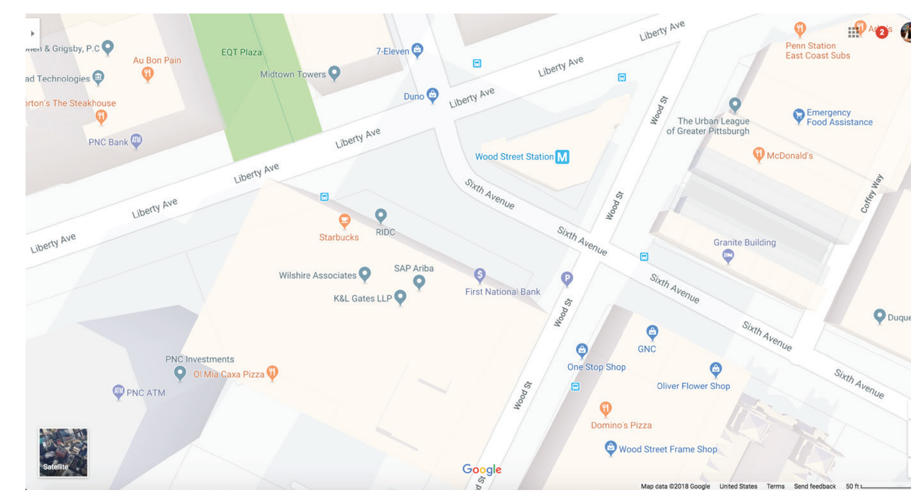


Figure 2.3.2. Six transit stops are located in the same intersection in downtown Pittsburgh area [14]

2.4. SUMMARY: DESIGN OPPORTUNITIES

The philosophical and the practical analysis of wayfinding indicates the role of emerging technologies in the near future. Ultimately, these below questions will be the promising opportunities to them:

01 | How might the new technology deliver semantic information?
: The concept of wayfinding infers that the shortest route is not always the right answer to the pedestrians. The new wayfinding solution should allow them to find ideal routes and make a decision with the semantic information

02 | How might the new technology care for the users?
: Ideally, semantic wayfinding will increase the users' ability to explore an unfamiliar urban space and knowledge of the surroundings. This will eventually foster the users' confidence in the urban adventure.

03 | How might new technology create seamless information search experience?
: As mentioned in Target Context, one of the major problems in the current wayfinding experience is digital fragmentation and high interaction costs. The users should be able to pull information with simpler interactions.

PART II

SPECULATING ON FUTURES

03

ENVISIONING OUT-OF-SCREEN EXPERIENCES

3.1. REAL WORLD AS THE NEW WWW

The ubiquity of semantic information in the urban space indicates the possibility of using the space itself as a web browser powered by reality computing. The advance of augmented reality and object recognition technology enables the users to interact with the unseen information in the real space. In Chapter 3, I speculated how these emerging technologies might shift the paradigm of information search experience in the near future through previous projects.

In 1993, the early concept of ubiquitous space was introduced as a form of a small palmtop unit by W.Fitzmaurice. [15] He designed a spatially aware personal hand-held device that can detect situated information overlaid on a target object. Figure 3.1.1 shows that the user searches the information about the weather of Canada simply by putting his device on the map. To view other types of information the user should smoothly shake the device.

Flash forwarding to the recent years, the idea of pulling local information directly from the object has been again conceptualized as *Google Lens*, powered by mobile augmented reality and visual recognition technology. [16] Google Lens gives a more intuitive understanding of pulling information than the palmtop in a way that it allows its users to set up the scanning target. The smartphone can retrieve relevant information in one-step, without opening other applications. Fluid Lab at MIT also designed the augmented reality-based information search tool named Reality Editor. They illustrated the user scenario of searching products by filtering certain criteria through the camera view. [18] Reality Editor can not only recognize the target object but also add or edit features of it so the users can expand the function of their objects as they prefer.

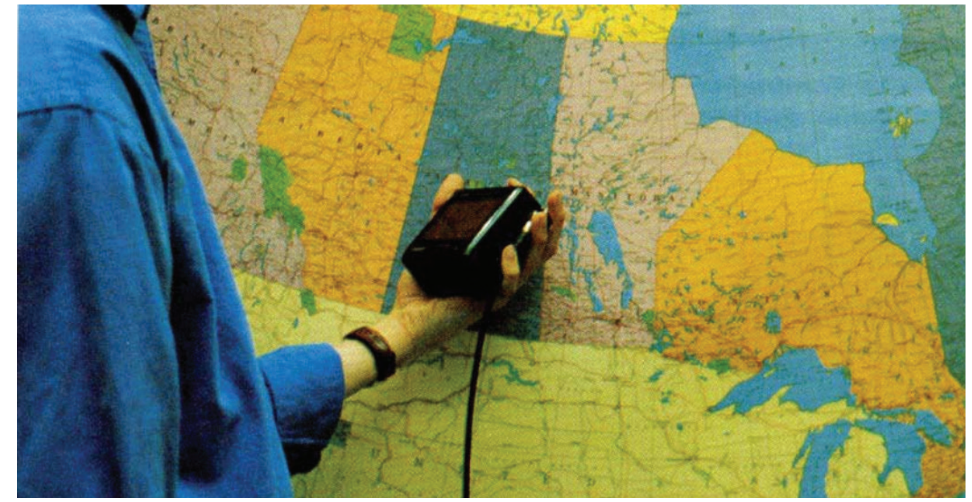


Figure 3.1.1 A hand-held palmtop unit that pulls information from the object [15]

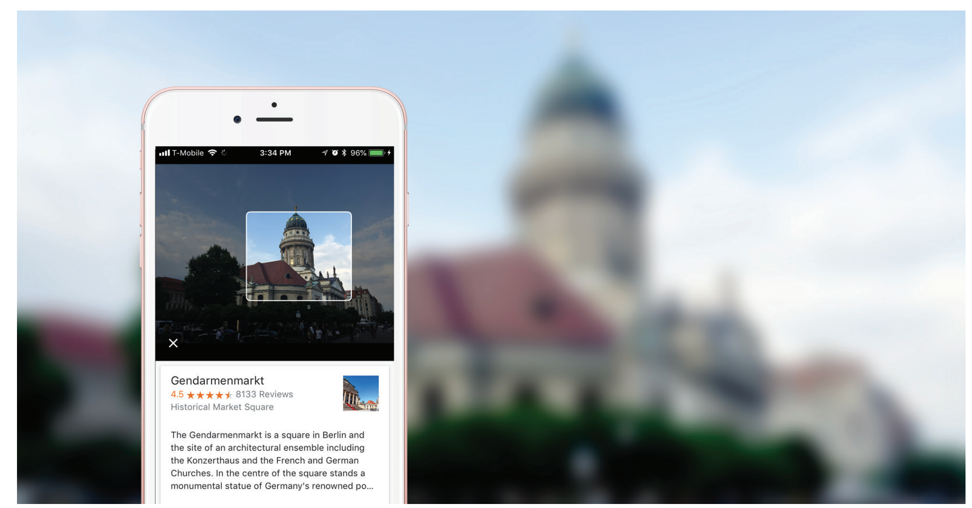


Figure 3.1.2. Google Lens [17]

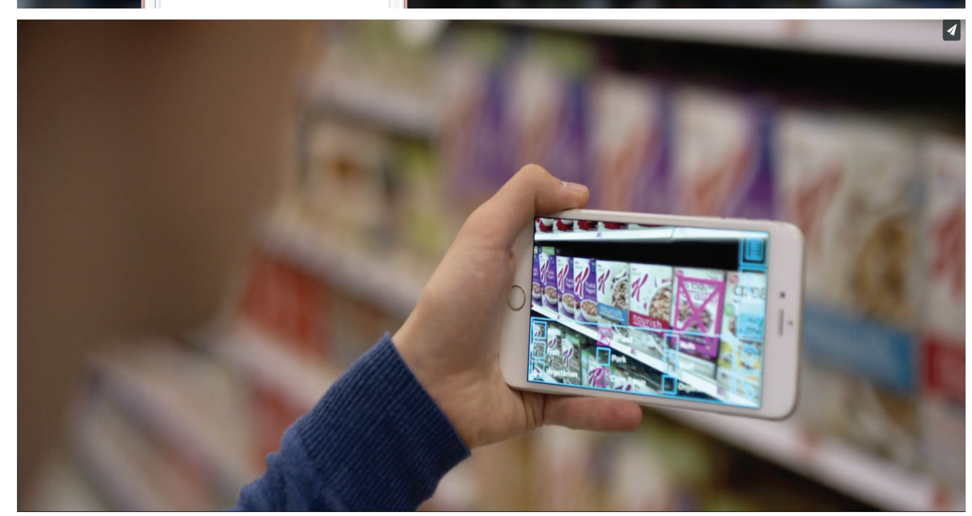


Figure 3.1.3. Reality Editor [18]

3.2. CHANGING THE ENVIRONMENT

The projects introduced in 3.1 have a commonality that the intervention of screen is still required. However, the development of head-mounted displays and spatial mapping technology will support out-of-screen experience in the near future. In their book, Bimber and Raskar (2005) suggested the possibility of spatial augmented reality, which detach the display technology from the user and integrate it into the environment with the support of immersive display. [19]

Several projects have been introduced to show the possibility of overlaying and seeing situated information without using screens. Takeuchi and Perlin worked on *ClayVision* (2012), a strategic environment morphing solution using 3D model mapping technology. [20] They used video feeds to scan the façade of nearby buildings and using the 3D models, they emphasized the form of those buildings by changing the size or overlaying point colors through as figure 3.1.3. Although they designed ClayVision for urban planning and they used the tablet for the demonstration, but the project indicates that façades can be the next information display.

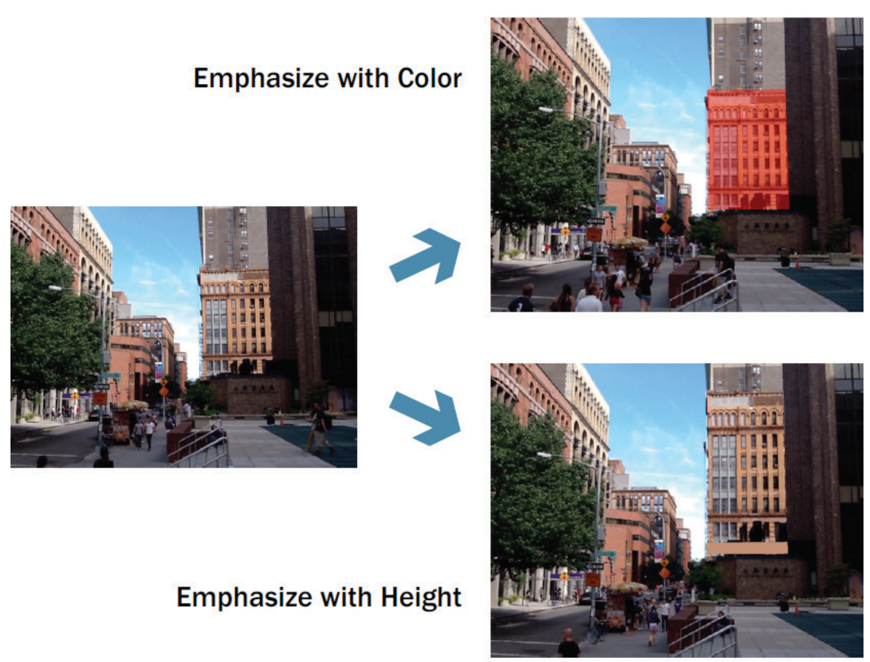


Figure 3.2.1. Emphasizing buildings with 3D model mapping [20]

Meanwhile, Lo et al.'s *ShapeShift* showed a small-scale, experimental object augmentation by extending physical properties of objects with augmented reality. [21] They applied the change of shade in both objects and surrounding environment to visualized an unseen attribute to the target object. Figure 3.1.4 shows that how the emptiness of a USB drive can be seen in the real world by applying a shadow with high y-offset, as if it looks like the drive is floating in the air. When the drive has no empty storage space, the surrounding surface will gradually cave in to express that the object is full.

Benko, Wilson, and Zannier introduced *Mano-a-Mano* (2014), a dynamic spatial augmented reality system that enables two users to interact with a shared virtual scene in a face to face arrangement. [22] Users can interact with the virtual objects directly without devices as the mounted projectors recognize the location of the human body. The distinct feature of *Mano-a-Mano* is that it supports multiple perspective views, which shows the possibility of displaying and transforming virtual objects by the different perspective, making the experience more realistic.

All projects indicate that the importance of depth recognition in the real space. In fact, one of the most critical parts of spatial augmented reality is depth perception and understanding obstacles in front of the target object, as overlaying the virtual information on obstacles would decrease the accuracy. Urban space is complex environment since there are multiple objects aligned in the same field of view and building are blocked

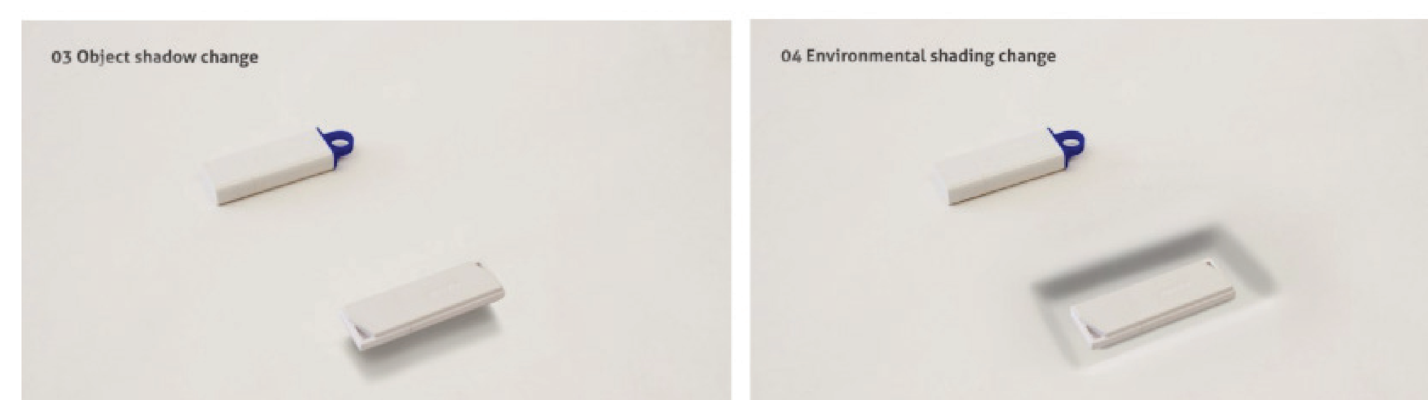


Figure 3.2.2 Dropping a shadow to indicate available storage of a USB drive [21]

by cars, signs, plants and other buildings. Can the system understand the depth of aligned objects and display the virtual information?

Here, Leap Motion has recently announced the *Project North Star* (2018), a hands-free augmented reality platform that understands hand motions, and they demonstrate with virtual dice to show the possibility of immersive depth perception. [23] In their concept video, a hand blocks the virtual object and vice versa depending on the position of the obstacle. They solved the object alignment problem by changing the perceived scale of the virtual object by aligning three different cameras (The physical cameras, the virtual cameras exist in VR and human eyes). [24][25]

Although perceiving depth with the world scale is still a big challenge with today's technology, Leap Motion's experiment shows that it is possible to augment the virtual information and aligning it according to the depth to some extent.

3.3. ZERO UI

One another technology needs to consider for out-of-screen experience is removing screen-based interface including visual UIs and touch interactions. The most commonly used natural inputs are gaze, gestures, and voice, which can also be applied to interact with the urban space. On top of that, the system should be able to aware the context of questions and display the information they want to search.

Microsoft's Hololens has already introduced the combination of using gaze, gesture and virtual assistant (Cortana) to interact with the real space. However, Hololens had a clear limitation for providing an immersive experience. First, the set of gestures it used is not based on the natural gesture. Therefore it takes some time for its users to learn. Second, although the virtual assistant can be used to interact with Hololens, it can't be used to manipulate virtual objects. (However, it is possible to build a custom app that supports object controller with voice interaction) These limitations make the user experience less intuitive.

That being said, Hololens suggested that multimodal interface can give more freedom and accuracy to control virtual objects. It's just a matter of how to design. Goose, Sudarsky, and Zhang worked on SEAR (Speech Enabled AR), a vision-based localization AR framework in 2003. [26] They designed a context-aware augmentation system for maintenance technicians and help them communicate each other through speech interaction. The system understands the information they want to share and overlay visual information on the space.

Meanwhile, Irawati et al. (2006) developed an AR application combining speech and gesture. [27] They designed three types of interfaces - gesture only, speech + static gestures, speech + dynamic gestures - and compared each other by measuring the amount of time users took to finish the task of arranging virtual furniture. Their experiment indicates that rather than relying on one type of interfaces, it is more intuitive and easy to learn to use multimodal interface for manipulating virtual objects. However, they noted that it’s important to match the speech and gesture input modalities to the appropriate interaction methods. [27]

04

CONSTRAINTS IN REALITY COMPUTING

While chapter 3 described the feasibility of out-of-screen experience, this chapter is to discuss the existing limitations of the emerging technologies, specifically augmented reality and multimodal interactions. Because of its distinct trait, - overlaying virtual information on a real space - augmented reality is influenced by various kind of factors ranging from cognitive load to environmental constraints.

I categorized these factors as two types; the first one is controllable constraints, mostly related to human factors and the second one is uncontrollable constraints coming from technical issues and the environment. Understanding these limitations will help design better spatial augmentation experience.

4.1. CONTROLABLE CONSTRAINTS

Livingston claimed that human factors were recognized as a critical element of the system development in the early work. [28] Indeed, the physical and psychological burden might hinder the users' willingness to use the technology in the long term. That being said, I labeled human constraints as 'controllable' because the effect of them can be removed by human-centered design.

One of the most challenging human constraints is discomfort in arms. Regardless of the type of devices, the current technology requires the users to keep holding their arms up to their eye level to interact with virtual information. To minimize this constraint, the designer might consider two things; for the mobile AR experience, design the scanning moment short. For the head-mounted displays, combining gaze and voice interaction instead of gaze and gesture or considering adopting a controller.

Another critical human constraint is the cognitive load. The users might have more mental overload when transitioning of attention between the virtual information and the target object/space. [29] In their paper, Kim and Dey pointed out that the separation between virtual information and physical spaces produces cognitive distance for users because they should keep switching across spaces to extract targeting spots from information displays and then apply the information to real-world situations. [30] The literatures on cognitive load indicates that the virtual information seen in the real space should be simpler than the information we see on screen because reading and understanding information itself already requires a significant amount of cognitive process as Stedmon and Kalawsky pointed out that losing the balance of visual complexity between the virtual information and the real world background hinders cognitive functioning. [31] Also, overload of information might occlude important information in the real-world scene. [30]

From the literature, I concluded that human constraints in the augmented reality experience are caused by adopting screen-based user experience. Displaying text-heavy information might not be appropriate to the spatial augmentation and 'clicking' it in the space would not as comfortable as doing the same motion with screen devices.

4.2. UNCONTROLABLE CONSTRAINTS

Even if designers can improve spatial augmentation experience more user-friendly, there are external constraints coming from surrounding environment which is very hard to remove. The biggest constraints that hinder spatial augmentation experience is sunlight. Sunlight takes the huge part in augmentation experience since it affects to hue and brightness shift, which both influence in the users' readability. The dimming and any hue shift can affect the virtual objects on the display surface as well as the real objects behind the display surface. [32] For example, the users won't be able to recognize the virtual information written in white in front of a bright colored wall. In the urban space, hue shift often combines with the shift of texture. Gabbard et al. found that there are large perceptual shifts between a 'no-background' condition and brick, foliage, pavement, sidewalk and white background conditions. [33] In his study, Livingston also showed that the same text information can be recognized differently depending on the texture of the background. [32] He suggested changing either the color of visual information or font size according to the texture shift.

Brightness shift is another critical factor caused by sunlight. When it's too bright outside, it is hard to read the digital information in the display. Livingston et al. pointed out that sunlight is

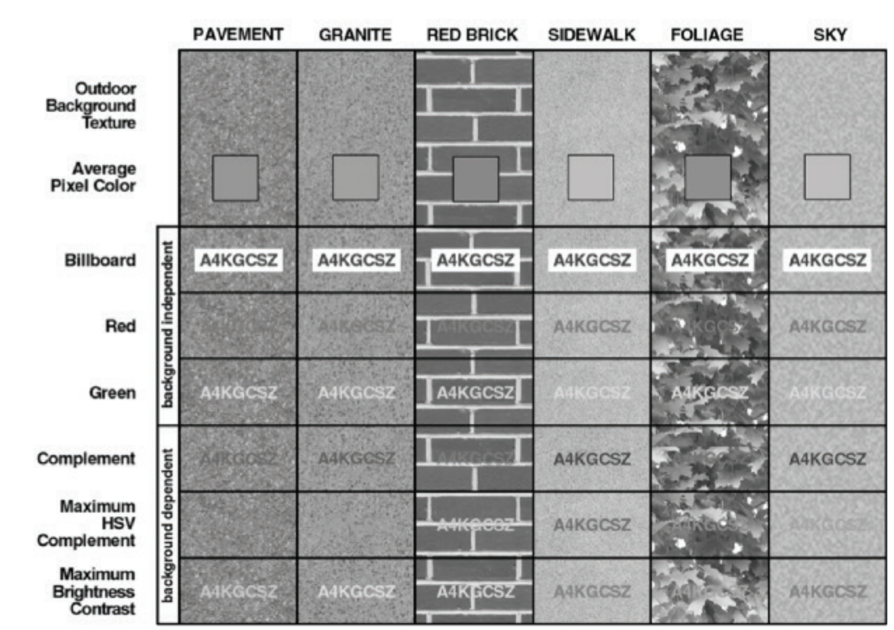


Figure 4.2.1 The different level of perception by different types of textures [33]

far brighter than any AR display, hence the mask or a similar filter would be a critical element of a successful optical see-through display for outdoor use. [32] The readability is improved in the dark, but low light cause another problem - it's getting hard to map the virtual information to the target space as the AR system can't recognize the environment. Figure 4.2.2 shows that the system can't recognize the target object through the camera.

Unlike human constraints, it is impossible to remove the technical and environmental constraints. However, designers might be able to reduce the influence from them by designing visual information responsive according to the change of the background.

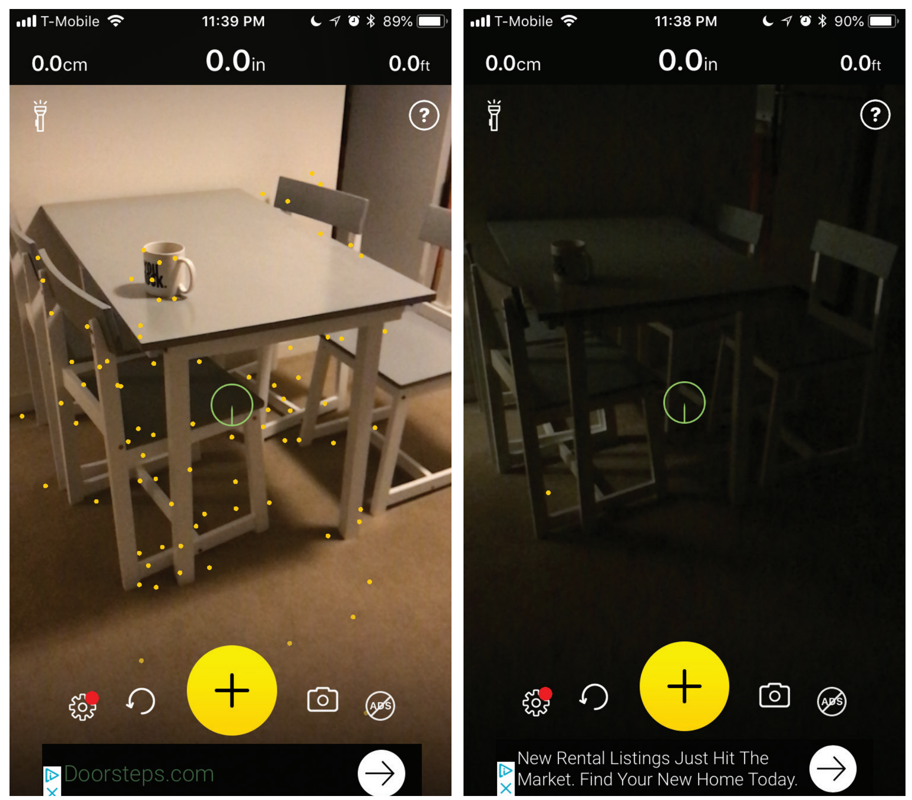


Figure 4.2.2 It is hard to recognize the target object in the dark [34]

4.3. SUMMARY: A FEW CONSIDERATIONS

From the previous studies, it can be assumed that the spatial augmentation experience might have the same challenges in the near future. Despite the advance of technology, the limitation coming from human factors and environment will remain the same. The literature review implies a few design implications should be considered for more user-friendly and feasible spatial augmentation experience as follow:

- Keep the moment of scanning environment short and necessary.

- Do not display virtual information all times - give users more room for understanding the real environment and more controllership to select and view information

- Use less screen-based UIs (texts, buttons, icons) for augmented information

- Control the virtual information with gaze and voice instead of gestures

- Giving more flexibility to the visuals: Maintain the high contrast between the virtual information and the real space by adjusting colors of the UI elements or adjust the size of the UI elements according to the background texture.

PART III

DESIGNING REACTIVE URBAN SPACE

05

DESIGN RESEARCH

Based on the literature review, I reframed the wayfinding experience as an exploratory movement, and it can be fully supported by semantic information. To design the feasible future, some constraints were considered, and I pulled the design implications on how to cope with them.

I conducted full-extent design research to understand user's behavior on wayfinding and learn more about their mental model. The research process consists of three steps; first, the online survey for investigating the pain points in current wayfinding experience. Second, the participatory design workshop including 1) user journey mapping, 2) semantic mapping and 3) design with metaphors. Finally, the concept speed-dating for initial prototypes.

Exploration

- Online survey to understand user behaviors on wayfinding activities

Idea Generation

- Group Design workshop with participants who are not confident in wayfinding
- Using *New Metaphor* framework to design spatial augmentation experience

Evaluation

- Concept speed dating and design iteration
- Build a working prototype using Vuforia and IBM Watson voice interaction API

5.1. EXPLORATION

To understand the pain points in current wayfinding experience, I conducted an online questionnaire on the user behavior on map-reading and wayfinding. The survey was done for a week, and 40 people participated in responding. Questions are designed to validate four hypotheses.

1) There is a strong correlation between user's ability to understand map information and his/her wayfinding performance.
2) Users who are not familiar with the house-numbering address system would feel harder to find their destination based on the text address information
3) Users would spend the most time on orientation
4) Communicating with other people might help users to verify their route

From the result, it was hard to find a correlation between map-reading ability and wayfinding performance. The research study done by Lobben also pointed out that there might be other cognitive factors that affect one's wayfinding ability. Yet, her study indicates that users' ability to navigate with a map may be based on their self-location ability in part. [10] For the second question, the survey wasn't well designed enough to find the relationship between the familiarity with house-numbering address and the ability to finding a destination, but the result indicates that a number of people cannot find their destination only with the text-based address. Meanwhile, the questionnaire shows that the users experience a bottleneck on orientation and self-location during wayfinding. On top of that, the participants also responded that comparing map

information with the real environment takes a significant amount of time and effort. Finally, I found that verbal communication between the user and other people doesn't help enough to navigate mainly because 1) the verbal guidance is often not clear and 2) the direction is either too complicated or inaccurate. In addition, most participants answered that it is basically not comfortable to ask strangers.

Along with the hypotheses, the survey also included the series of questions about pain points they experience during wayfinding. Below are key takeaways I found from the result:

1) Users make the most mistakes while getting oriented at the beginning and after getting off the public transit (bus, subway, train, etc.)
2) The moments when users need verification is the moment of transition (ex. by foot > by bus > by foot) and making turns
3) Using an unfamiliar public transit often causes a huge amount of delay
4) In most cases, users tend to search information on their destination before departing

From these findings, I pulled two research questions: first, what is the most common strategy for users to get themselves oriented and verify their location? And if unexpected events happen at the destination and the user cannot do a task at there, how would they find an alternative?

5.2. IDEA GENERATION

After the exploration, I conducted an idea generation workshop with 8 participants. The workshop consists of three sessions - user journey mapping, semantic mapping, and designing the future with New Metaphor toolkit.

For the user journey mapping, I asked the participants to recall the moment of the most recent wayfinding experience in an unfamiliar urban space and draw a journey map including their emotions and information they used for the wayfinding. (Figure 5.2.1) I could find three commonalities from 8 journey maps.

1) The participants felt frustrated when they experience unexpected delay due to traffic, schedule change of public transportation and so on

2) It takes a lot of time to find an exact location of their destination, especially in a densely built area.

3) Similar to 2), it's harder to find a right turn point when the road forks to multiple other roads.

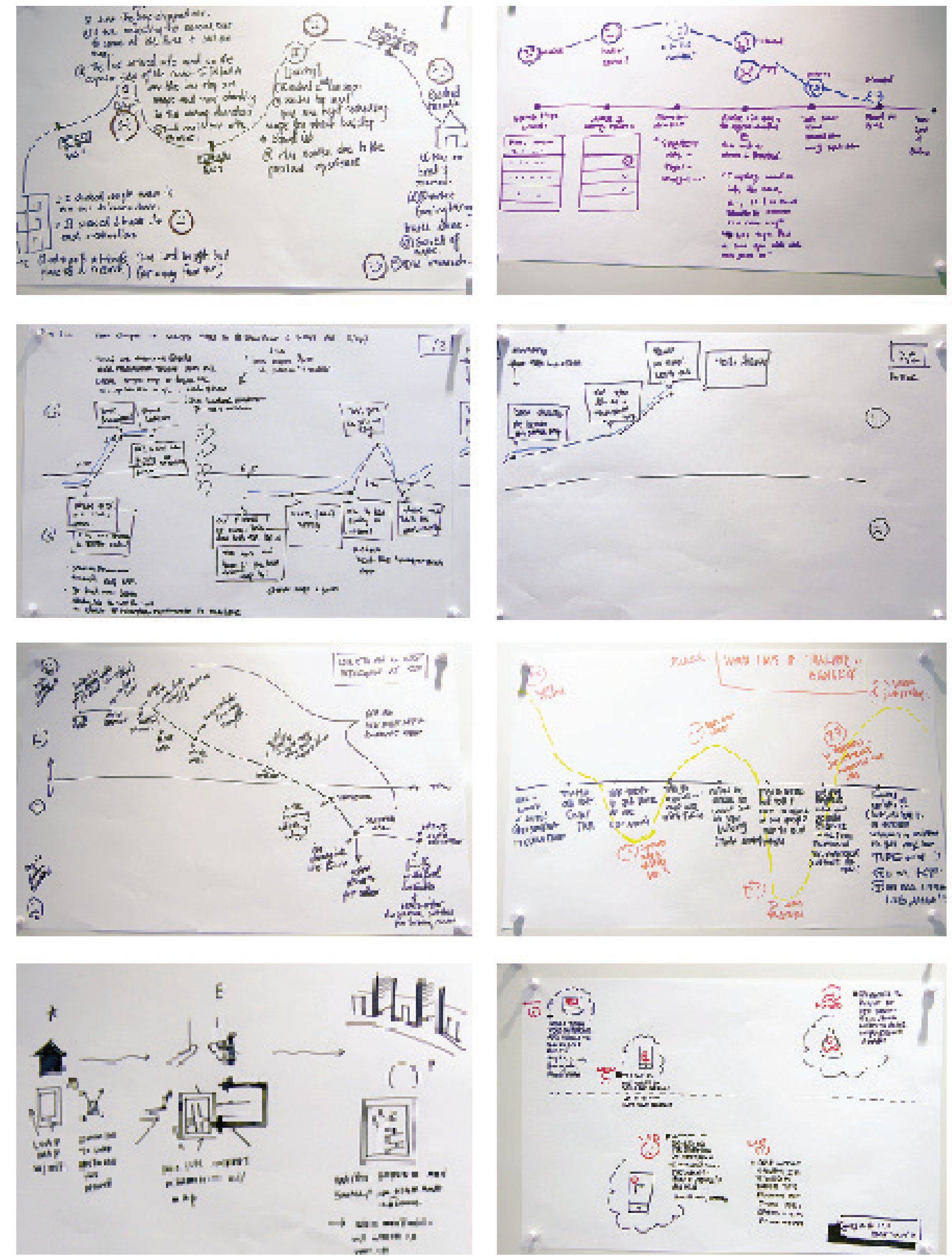


Figure 5.2.1. User journey mapping results

One other thing I found from the journey mapping activity is that there are various purposes for wayfinding. The reason for wayfinding ranges from social activity to exploring the best restaurant in the city. While the former is more for purpose-oriented, the latter is for learning about what's in the user's vicinity. This indicates that the semantic wayfinding solution should be designed to support all different purposes of wayfinding.

To figure out the types of semantic information, I asked the participants to draw a semantic map about their general past wayfinding experience, and 7 participants completed the activity. Semantic mapping activity is useful to find out what kind of peripheral information is needed to complete wayfinding. Also, it shows the users' mental model on the wayfinding activity by going deeper into the users' mind. The mapping results imply three key points as follow:

1) Users use 4 to 5 different applications for wayfinding, which validates the phenomenon of digital fragmentation discussed in Part 1

2) Rather than looking at the navigation route all the time, users tend to memorize key referral points and walk without seeing map

3) Along with the needs of basic navigation information, users also want to get the general information about the target area to learn more about the neighborhood including the history of a place, reviews, ratings, landmarks and so on.

Figure 5.2.2. Semantic mapping results

At the end of the workshop, the participants were asked to pick one or more semantic information they want to visualize and design the 'magic technology' experience for the better wayfinding experience using Dan Lockton's New Metaphors research method. (Figure 5.2.3) The intention of New Metaphors workshop is that the process might be something designers can use or adapt for idea generation, or to provoke new kinds of thinking about interface design. [35] For this design workshop, a random selection of 75 multisensory metaphors are used. 5 participants finished the entire generative design session.

From the observation, I found three important implications. First, a lot of users chose the visual metaphors from nature to visualize the semantic information. For example, one participant used the image of the cloudy sky and rainy weather to express the traffic jam. The other example is using footprints on the snow to visualize the navigation route. The reason for their selection might be coincident, however, it can be assumed that they were able to connect the attributes of nature and those of the semantic information in a short period of time. In her paper, Vierra pointed out human's tendency to solve problems with inspiration from nature. [36] I assume that biomimicry design gives more instant and intuitive understanding to the users, therefore, using the visual metaphors from nature might reduce the cognitive load to proceed the information.

Second, the participants often utilized the façade of buildings to visualize the navigational information. They used a point

CHAPTER 05 | DESIGN RESEARCH DESIGNING REACTIVE URBAN SPACE

color to emphasize the destination or overlay the verification reference on the building surface. This result resonates well with the concept of ClayVision discussed in Part 2 and indicated that the façade can be used as the display surface in spatial augmentation experience. Also, the result might also imply that the previous concepts for AR navigation are not user-friendly. The fact that the participants prefer to overlay the navigation information on buildings connects to their needs to see the visual guidance at their eye level, while most AR navigation applications overlay the route on the road surface. Putting navigation information out of the eye level might cause not only physical discomfort but also fatal accidents.
Finally, during the observation, I noticed that the participants designed experience of loading one semantic information at a time. This can be interpreted that users do not want to see an excessive amount of information simultaneously. Or, it can also be assumed that they want to control the amount of information.

Besides these implications, the design workshop with New Metaphors also

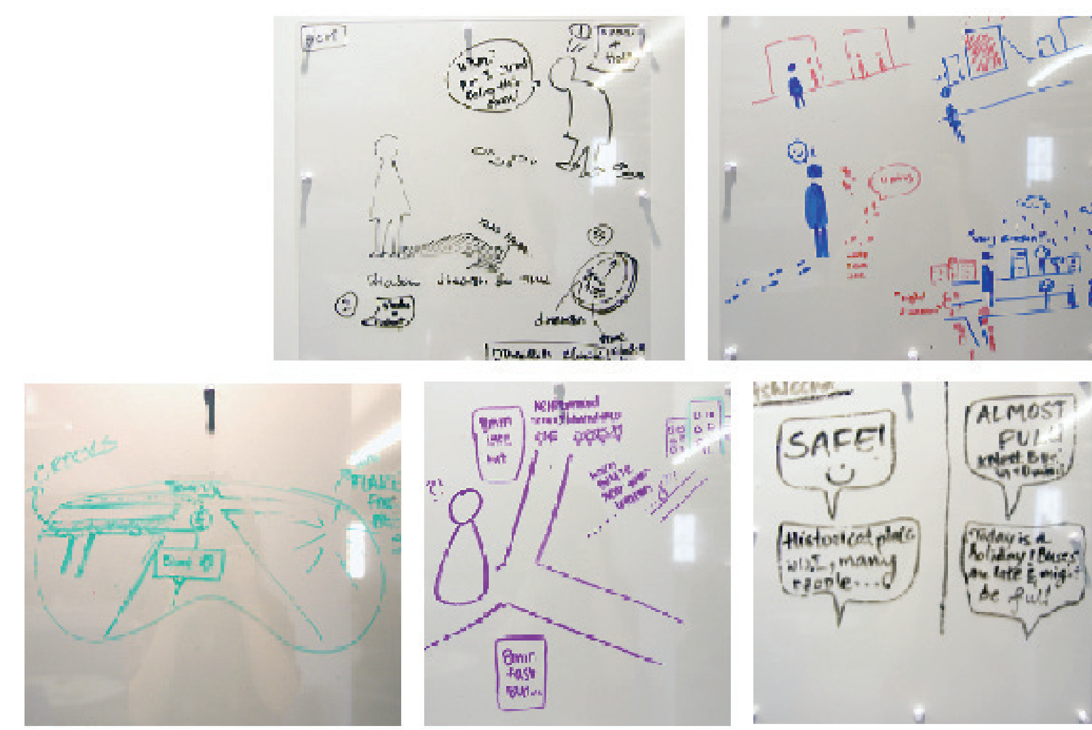


Figure 5.2.3. Participatory design workshop results imply the strong needs of spatial augmentation and self-oriented information

answered the two research questions I had from the online survey. During the visualization activity, I could find that the participants have a strong needs to see orientation/verification information in self-perspective view. As seen in Figure 5.2.3, they use the metaphor of shadow and footprint to visualize the information. Both metaphors have a common attribute in a way that they are originated from oneself. Meanwhile, for the second question, - dealing with unexpected incidents - the metaphor workshop result indicates that the participants prefer to 'foresee' the advisory notification before approaching so that they can avoid entering the target space. For example, one participant visualized the traffic information with the crack on the road, intending not to enter the road to avoid the possibility of delay.

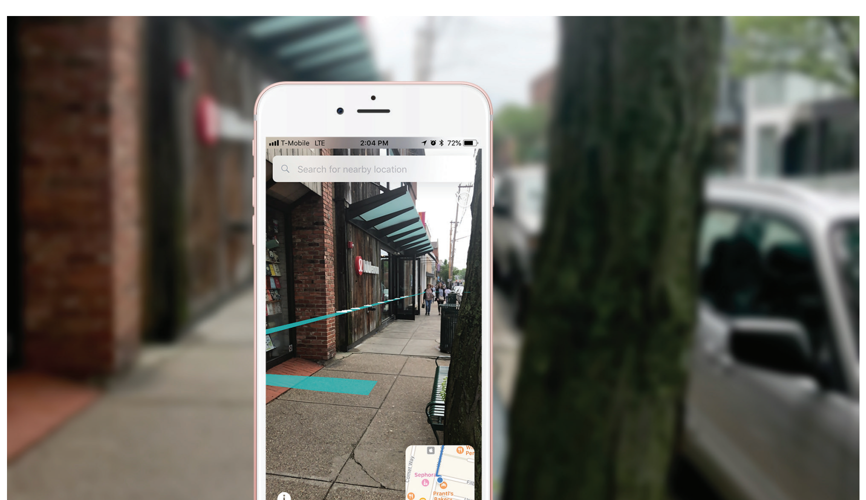


Figure 5.2.4. AR navigation apps require users to keep looking at the phone screen, which causes a lot of physical discomfort and any accidents [37]

5.3. SYNTHESIZING

Figure 5.3.1. A set of the most commonly searched semantic information during wayfinding

Considering both the mapping activity results and the participants' storytelling during the workshop, I picked 16 types of semantic information regarded as important or commonly searched by the workshop participants. As seen in figure 5.3.1, some kinds of semantic information such as free wifi, store inventory and public restrooms do not seem to be related to wayfinding activities, but they play an important role in user's overall experience in a way that they are all related to the tasks needs to be done at the users' destination. If these are not available at their destination, then it is no point of traveling.

Then, I rearranged the semantic information cards by user journey to figure out when exactly those types of information are needed. Generally speaking, wayfinding activities have 4 phases - orientation, route decision, route monitoring, and destination. [38] While the navigation information is used in all phases, the semantic information is needed for a certain phase. Figure 5.3.2 shows that the majority of semantic information is needed in the destination stage, meaning that a lot of the semantic information is related to the current status of a destination. This includes opening hours, crowdedness, average price, ratings, store inventory and so on. Also, I found that some semantic information is involved in route decision and route monitoring phase including traffic, safety, road closure, and accidents. These types of information are also involved in the real-time status of a route.

This activity implies two possibilities

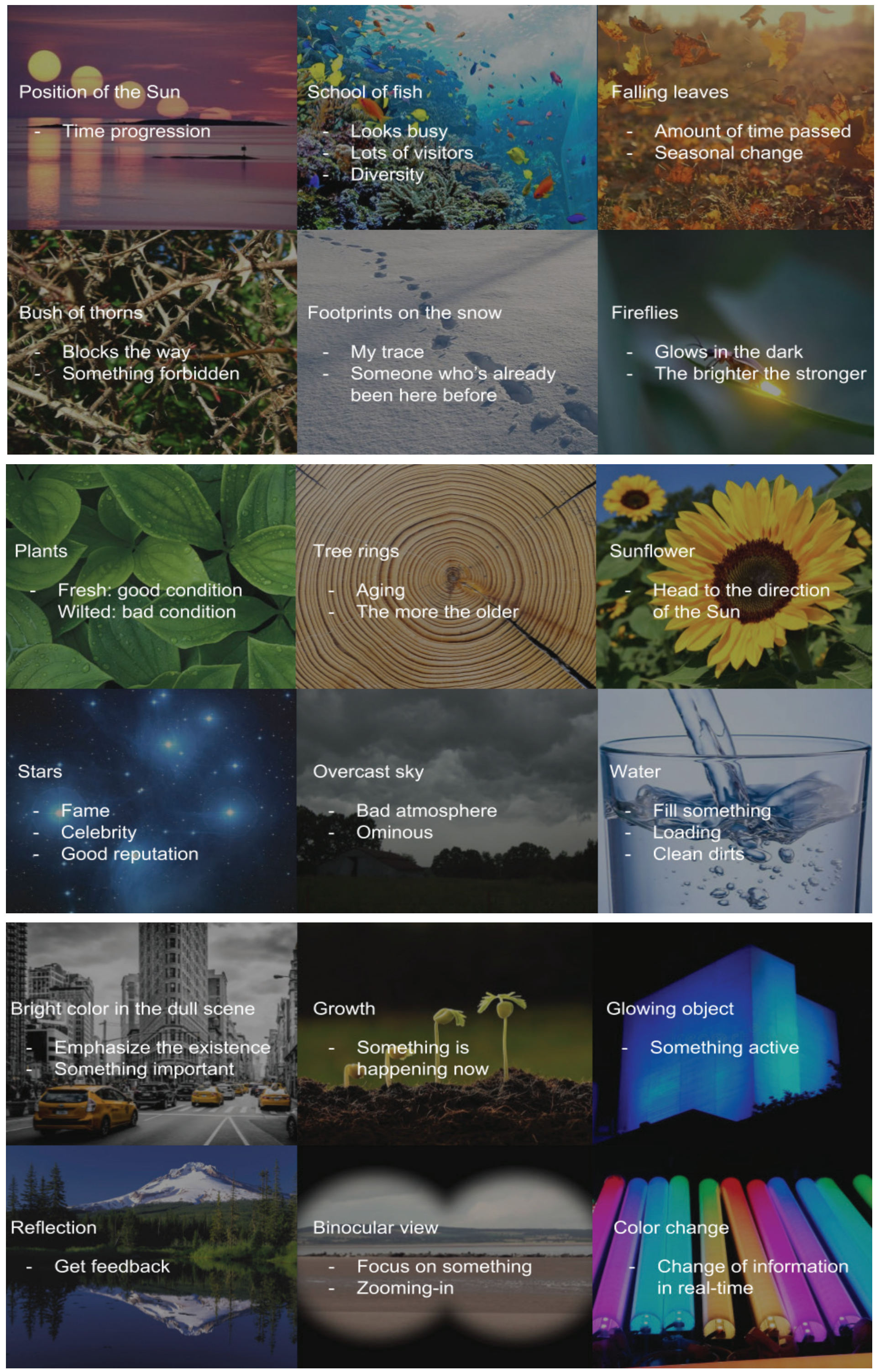


Figure 5.3.3.
Metaphors used for structure mapping and their attributes

Figure 5.3.2. The semantic information is most needed at arrival

of semantic wayfinding: first, semantic wayfinding enables more flexible urban exploration experience as it gives plentiful information for decision making. Second, it is the 'current status' that determines the ideal navigation route - if there is unexpected traffic in the shortest route or if the destination business is closed now, then it cannot be the best decision.

Finally, referring to New Metaphors workshop guideline, I categorized the semantic information by characteristic and then made connections between it and the metaphors from nature. 'Structure-mapping' between the Thing 1s (the semantic information) and Thing 2s (the metaphors from nature), facilitates to identify which features might actually make sense for the metaphor to work. [35] For this activity, I made a new card set of nature metaphors and wrote down the attributes of each metaphor. Then, I pulled the queries related to the semantic information and mapped with the attributes of the selected metaphors.

Figure 5.3.4.
Structure-mapping results

5.4. CONCEPT EVALUATION

Based on the results of structure-mapping, I made initial sketches of each semantic information as seen in figure 5.4.1. The basic assumption of this concept is that users might be able to understand the meaning of the organic visuals without any text information. Also, I assumed that the moment of spatial augmentation and information process becomes shorter since the users don't need to spend time on the interpretation of the visuals. The concept includes the multimodal interaction of gazing and asking in order to pull the semantic wayfinding information into a target space.

Instead of creating prototypes with graphic design tools, I chose a couple of semantic information and made simple video prototypes by combing the screen saver animations and the short footage of a building. The video prototypes illustrate how the semantic information is overlaid on the façade of the building. In this way, participants would be easier to understand how spatial augmentation works since the visuals are designed to be augmented in the 3D space.

With the video prototypes, I conducted concept evaluation interviews with 6 participants. Each participant watched the video prototypes and said aloud what works and what doesn't work.

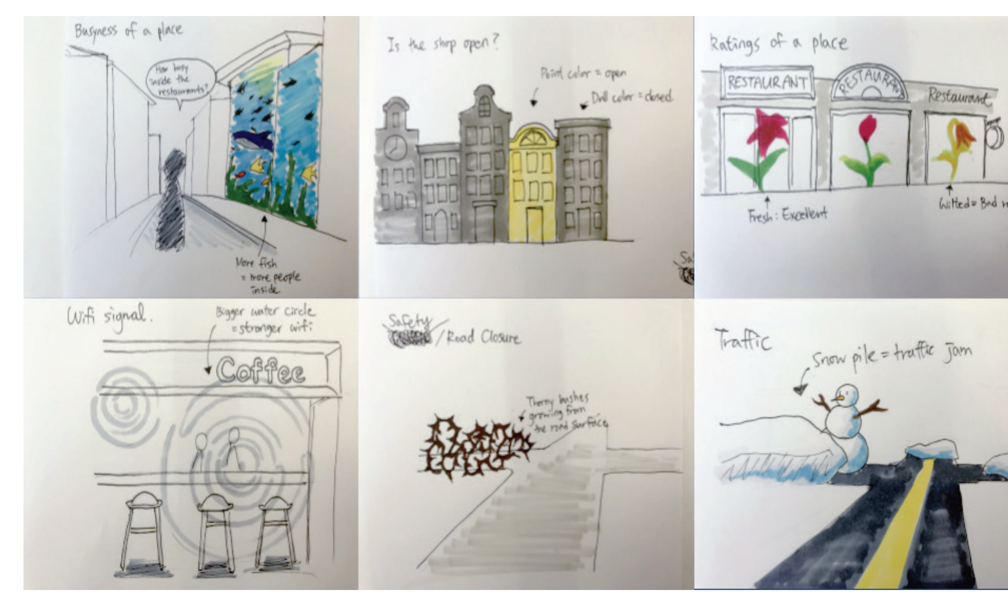


Figure 5.4.1.
The initial ideas for visualization of the sematic wayfinding information

The feedback on the first video prototypes was mixed. For the positive notes, the participants answered the visual is pleasant and easy to see at a glance. However, they said that it is hard to understand the meaning of the visuals unless they know what the purpose of the building is. Rather than using the image from nature, some participants suggested using universal symbols for better understanding. Also, they mentioned that if the augmented information is presented all times, it would not only block the image of the real space but also cause mental overload.

The first prototypes have two important implications; first, rather than applying raw images of the nature metaphors, focus on their color and form factors. Using the raw images didn't deliver the meaning successfully, as a lot of participants answered that they seem more for a stress reliever. Second, consider combining symbols or simple icons to give a clear context of the information. A lot of participants mentioned that they would want to learn more detail about the augmented information. For example, if they see availability of public wi-fi, they would also want to know if it is secured by a password or not.

With the implications in mind, I iterated the video prototypes and got instant concept evaluation feedback from 6 to 7 participants in each iteration step. Through the iterations, I tested three variations of each semantic information and got feedback on the different combinations of colors and forms.

Figure 5.4.2.
An initial video prototype used for concept evaluation

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During the concept evaluation process, I got several key takeaways to keep in mind.

• Color is a very important factor to deliver the meaning of information. When seeing a color, people tend to associate a specific meaning they already learned from other designs. Also, using more than three colors at the same time might bring confusion to users.

• Simplify the form rather than using organic textures. When it comes to express quantified data, give a clear difference between different figures (ex. Larger form for a stronger wi-fi signal)

• Consider using animation to show the change of status and give a better comparison between options.

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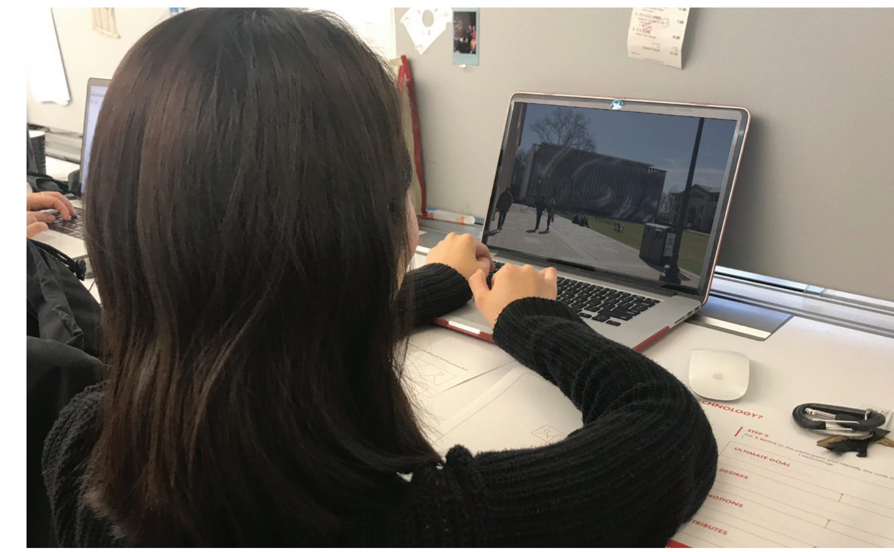
• Consider using animation to show the change of status and give a better comparison between options.



5.5. PROTOTYPING

After finalizing the UI design plan, I built a working prototype with a set of selected semantic information visuals and designed a question-and-answer experience with voice interaction. For prototyping, IBM Watson speech interaction API is used to create the conversational interface, and Vuforia augmented reality solution is used for spatial augmentation experience. The prototype application is built to support mobile AR. Because of the technical limitation in real-time 3D rendering, I took 2D images of downtown Pittsburgh area and overlaid the UI animation with Vuforia solution. After Effects is used for the UI animation.

Figure 5.5.1 Indoor prototype demonstration

06

BIOPHILIA: SPATIAL AUGMENTATION UI

The spatially-augmented semantic wayfinding solution, branded BIOPHILIA, is designed to support easier walking travel and give pedestrians more confidence in urban exploration experience. BIOPHILIA is a result of the speculative design process to forecast the technical trajectory in the future and to suggest how the emerging technologies might care users in a positive way.

BIOPHILIA is an integrated urban information platform that provides all different types of semantic wayfinding information instantly with pleasant, nature-inspired visuals. While experiencing the system, the users will feel like the entire urban space reacts to questions they ask.

6.1. BIOPHILIC MINIMALISM

The key concept of the UI design is 1) biomimicry and 2) minimized screen-based information (text and icons). There are three design principles to design the visuals. First, rather than presenting all details, the system focus on one or two information that is critical for users' decision-making process. In this way, the system doesn't burden the users' cognitive process nor block their field of view with an excessive amount of visuals. Second, use the organic texture to give higher contrast between the augmented information and the urban space. Urban areas are filled with man-made structures, meaning that using nature-like images can be looked more salient in artificial environments. Finally, the biophilic design gives more emotional pleasure to users, particularly effective in stress relieve, as Ryan et al. claimed that natural environments are generally preferred over built environments as there is evidence for stress reduction related to both experiencing real nature and seeing images of nature. [39]

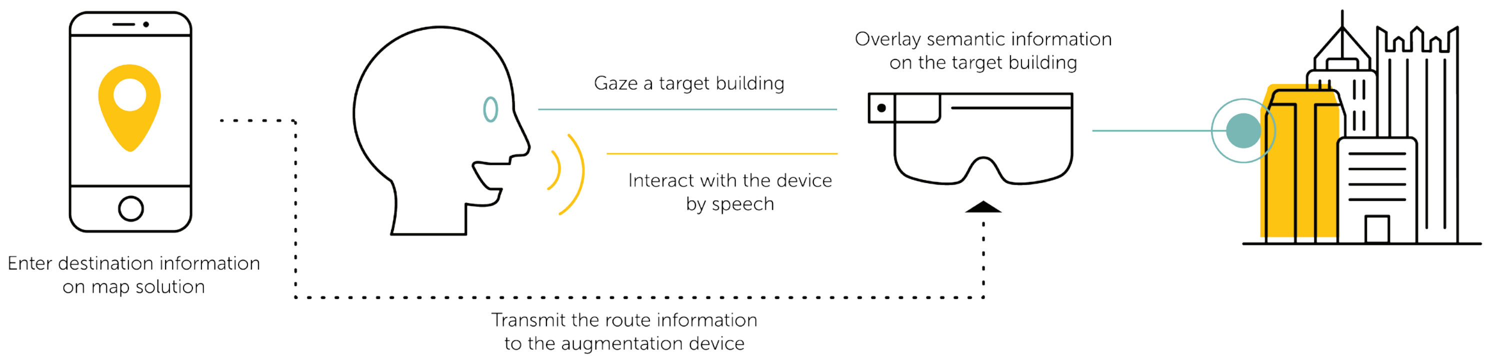
6.2. INTERACTION MODEL

Depending on the characteristic of the semantic information, the way to pull it should be different. Before design the interaction model, I categorized the semantic wayfinding information by 1) Passive Information and 2) Active Information as seen in Figure 6.2.1. Passive Information is to prevent the users from any delays or dangers including traffic, road closure, accidents, crime alerts and orientation/verification guide. Passive information should be provided automatically even if the users don't request, so it can be delivered before approaching the advisory area.

The rest of the semantic information is labeled as Active Information, which can be seen only when the users ask to the system. By limiting moments of spatial augmentation, the users may have more controllership in information display and feel less repulsion in the augmented reality experience.

Figured 6.2.2 summarizes how to pull the semantic wayfinding information by information category and device type. While active information is supported by both mobile and head-mounted display, I assume that passive information can be supported only by the head-mounted display at full extent, as there is a big interaction barrier in mobile AR experience that requires the users to hold their device up all times.

FOR ACTIVE INFORMATION



FOR PASSIVE INFORMATION

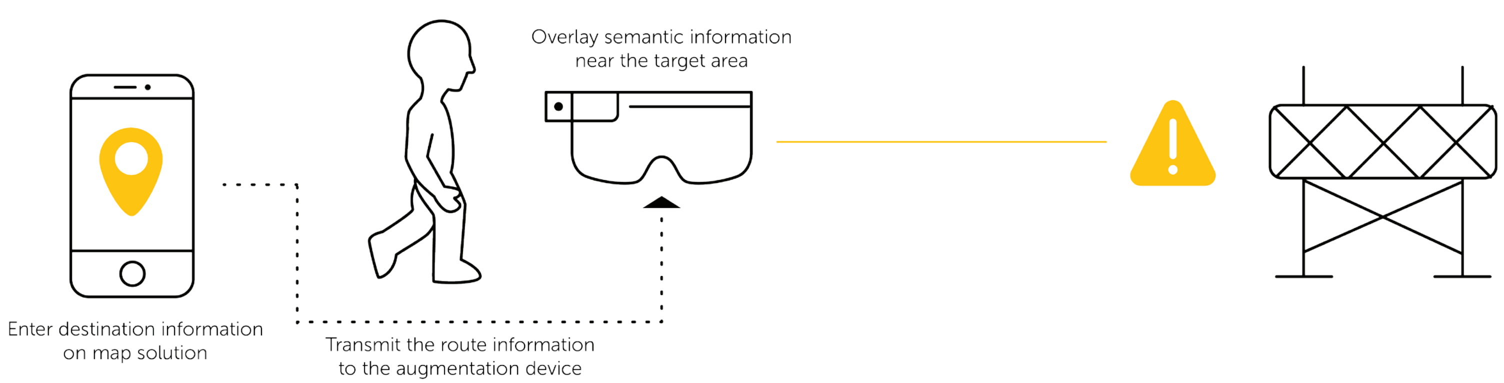


Figure 6.2.2
Interaction model by type of information

07

DESIGN SUGGESTIONS

As mentioned in Chapter 4, spatial augmentation experience and augmented reality technology still have a lot of limitations coming from surrounding environments. Unfortunately, the outdoor spatial augmentation technology is still at the R&D phase, therefore it is hard to forecast how the user experience would look like at full extent. That being said, it is not impossible to imagine how the interface would be seen in the real space. As mentioned earlier, I envisioned the future where the surrounding environment becomes an information browser. In Chapter 5, I juxtaposed existing web browsers of today and the real space. There are two big differences in between them. One is the background color and the other is the notion of depth. To design the better spatial augmentation experience, I suggest referring to the design principles considered for web design and the fabrication techniques for giving a better recognition of depth. For designing the final concept of BIOPHILIA, I referred to the principles from the various field of design including photography, web design, painting, and architecture.

7.1. DESATURATING BACKGROUND

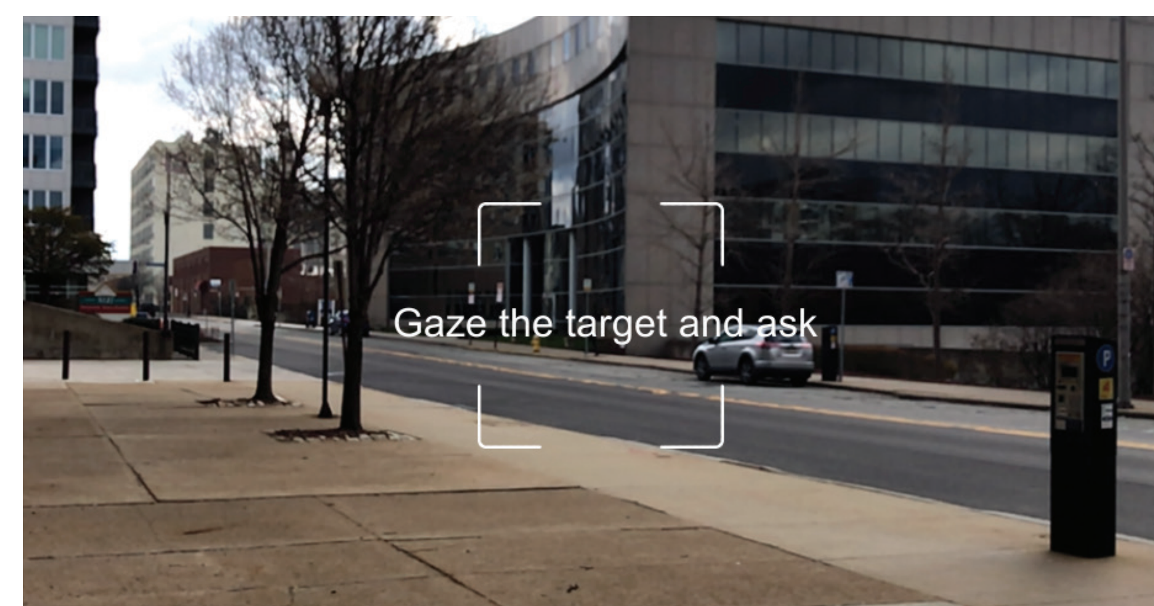
In order to give better contrast between the virtual information and the background, desaturating background might be considered to make the users focus more on augmented information. This suggestion can be supported by the research study done by Frey et al. (2008), as their experiment indicated that people tend to pay less attention to an image of desaturated man-made object/environment. [39] Their study result implies that putting desaturation effect on urban space might prevent the users from getting distracted by surroundings. Artificial environments like downtown urban spaces include hundreds of different colors. Therefore, reducing the number of hues may help the users distinguish the augmented information from the real space.

During the prototyping stage, I found that desaturating background should be considered especially when 1) the surrounding environment contains multiple different hues, 2) the tone of virtual information and the background is similar, and 3) more than two different colors are applied to the virtual information (ex. Opening hour). As seen in Figure 7.1., both augmented information and the target environment have warm yellowish tone, therefore, desaturating the color of the surrounding environment helps the semantic information being recognized better.

Figure 7.1. Desaturating the background environment makes the augmented visuals more salient

7.2. CONTRAST RATIO

One another thing should be considered for the gaze dot and speech feedback UI is the contrast ratio. The contrast ratio defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black). [41] In his article about accessible interface design, Babich said contrast ratio represents how different color is from another color and the higher the difference between the two numbers in the ratio, the greater the difference in relative luminance between the colors. [42] Lin mentioned that contrast ratio plays a key role in enhancing readability. There have been various suggestions about the 'goldilocks zone' of ideal contrast ratio for maximum legibility. [43] According to the study done by Wang and Chen (2000), visual acuity increased as contrast ratio increased up to 8:1 and then decreased once the contrast ratio was greater than 8:1. [44] Meanwhile, research by Richardson et al. suggested a luminance contrast ratio of 3:1 between symbols and backgrounds for web design. [45] Finally, the W3C Web Content Accessibility Guidelines recommended that small text should have a contrast ratio of at least 4.5:1 against its background and large text (at 14 pt bold/18 pt regular and up) should have a contrast ratio of at least 3:1. [46]



Based on the opinions from the literature review, I suggest an adaptive color correction for the UI elements that help maintain the constant contrast ratio between 4.5:1 and 8:1 for the interactive interface. The concept of responsive colors were already introduced by Ishizaki (2005) through his information graphics using the automatic simultaneous contrast adjustment. [47] Automatic contrast adjustment is also applied to commercial digital products. As seen in 7.3.1, Google Site automatically adjust both text color and background brightness and contrast to enhance readability.

There are 2 ways for AR interface to maintain high contrast. First, applying dark outer shadow to make it look more conspicuous. Or, adjusting hue and brightness entirely.

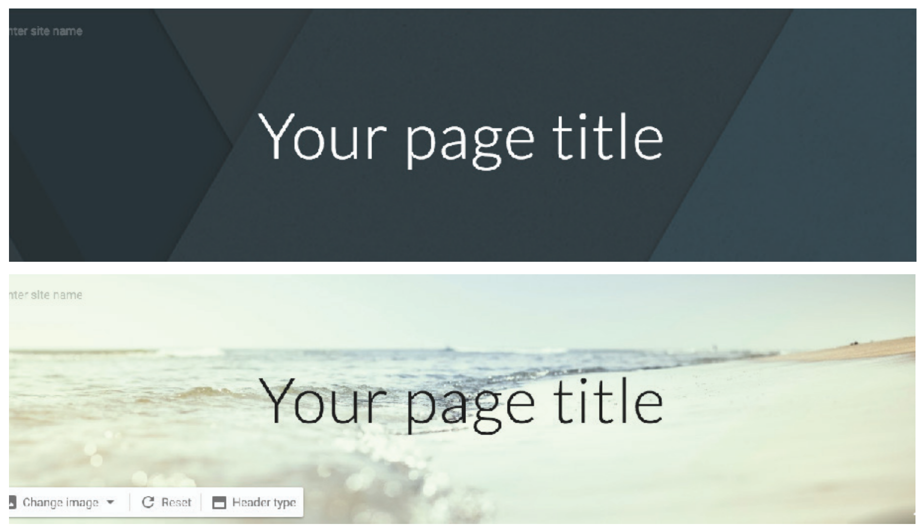


Figure 7.2.1. Google Site supports automatic contrast adjustment - the text color changes automatically when the background is changed [48]

Figure 7.2.2 shows how the white text in the AR view can be more legible by adjusting the contrast ratio. To measure the contrast ratio, I applied 'pixelate' effect on Adobe Photoshop and sampled the representative color of each photo. Then I entered the hex code of the sample color on the contrast ratio calculator and estimated the approximate ratio.

The contrast ratio of the first image seen in Figure 7.3.2 is 1.9:1. This means when the camera is facing the sidewalk surface, the contrast ratio falls significantly. If the system drops dark shadow behind the UI, the contrast ratio goes up to 4.3:1, and if the color of the UI changes to black, the ratio jumps up to 10.9:1.

Figure 7.2.2. The contrast ratio can be increased either by dropping dark shadow or lowering brightness

7.3. NOTION OF DEPTH

The farther the target object is, the harder the users map the virtual information, especially when the field of view is limited and multiple information is displayed in the same space. The current AR applications apply different scale on each icon to give a better notion of depth, but still, there is a limitation because the target area in the distance is often blocked by a building in front. Therefore, from the users' point of view, icons for the distant object are looked floating in the air as seen in figure 7.3.1.

I assume that spatially augmented UI will also have the same issue in the future because overlaying virtual information at distant perfectly is particularly challenging. Then how to give a better notion of depth?

The literature from photography, art and HCI suggest the possibility of fabricating depth with different level of chroma and color tones, rather than adjusting the scale of UI elements. Nakano et al. found that the effect of hue on the apparent depth increases as the chroma increases. [49] In his photography design guideline article, Rodin mentioned that warm colors appear closer to the viewer while cool colors appear farther in a dark background, while in a white background it happens on the other way (cool tones for a closer object, warm tones for a distant object). [51] Another point I could find from his color-depth chart is how chroma level can be applied to express depth. In a dark background, he used bright tones for objects in proximity and applied dark tones for those

Figure 7.3.1. it is hard to recognize the distance of UI elements especially when they are displayed in the same Space [37]

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in the distance. In a light background, he applied brightness on the opposite way. With those suggestions from the literature in mind, I designed two sample images for the spatial augmentation experience in daytime and in the night time. As seen in the figure 7.3.2, the semantic wayfinding information will be displayed with higher chroma level in proximity in the light environment, but the system will lower the chroma when it's getting dark. The glowing effect might also be considered to give better readability in the dark.

Figure 7.3.3 Applying different chroma level by the time

7.4. ADAPTIVE SCALE

The final thing to consider for the spatial augmentation experience is the scale of the UIs. In the final concept art, I overlaid the virtual information on the entire façade, yet that wouldn't always work well depending on where the users are standing at. If their target building is too close to them or if it's on the same side of the users, it would be hard to observe the virtual information.

To understand the relationship between human perspective and information display, I referred literature from architecture and industrial design, particularly about anthropometric design. In their book, Panero and Zelnik (1979) mentioned that the normal line of the sigh is about 10 degrees below the horizontal line when standing, and the magnitude of the optimum viewing zone for display materials is about 30 degrees below the standard line of sight. [51] Figure 7.5.1 is a diagram of estimating user experience based on their design guideline. The anthropometric approach on eye movement indicates that it would be more user-friendly to overlay the virtual information on an entire surface of a building when it is within the user's optimum eye rotation. If the building doesn't come inside this 55-degree view, it can be assumed that the augmented information should be scaled down so the user can see the information at full extent.

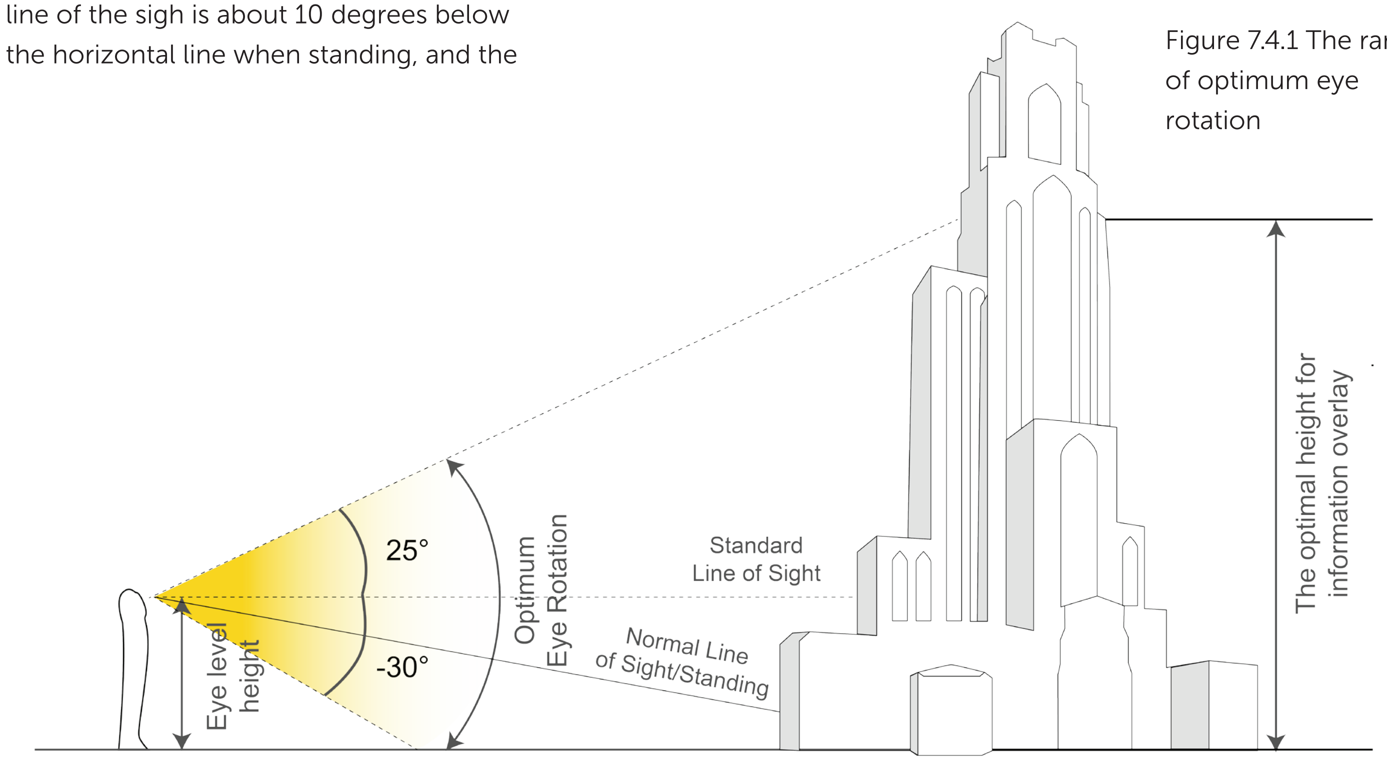

Figure 7.4.1 The range of optimum eye rotation

Then how to display the virtual information when the users are close to their target building? In their interactive media façade design project, Fischer and Hornecker (2012) separated the display as interaction space and display space to overcome the problem of different FOV. [52] They found that ground-level displays are more in reach-of-grasp when the players are closer to the interactive space. Their design project implies that the augmented information on a close target building would be overlaid on the ground floor.

Figure 7.4.2 illustrates the design suggestion for the adaptive scale. To minimize the distortion of the view, the virtual information will be slid to the front view depending on the users' perspective. It is scaled down to the height of a ground level of a building. When the users move far enough to be able to see the entire building, the system will use the entire facade.

Figure 7.4.2 The illustrations of adaptive scale UI

DISCUSSION

This paper suggests a possibility of semantic wayfinding experience with the process of speculating the future. Spatial augmentation still confronts technical limitations including real-time 3D rendering and outdoor spatial mapping. On top of that, head-mounted displays, expected to be able to fully support the spatial augmentation experience, are still in the development phase, making it hard to estimate the overall experience and build prototypes.

One another thing that should keep in mind that my suggestions on the design guidelines need to be further investigated after the released of commercial head-mounted displays and better spatial mapping prototyping tools. Nevertheless, I believe that the existing design principles will be valid to some extent since the influence coming from background colors, perspectives and human factors will be applied in the same way. Referring to the research studies on these factors will help designers estimate the user experience of the future.

Finally, when it comes to shifting hue and saturation of the environment and the augmentation UIs, accessibility should also be investigated deeper in the future, as there is a possibility that some type of color-blindness might not be able to recognize the spatial augmentation. Android system is supporting color correction settings for three different kinds of color blindness to enhance accessibility. Similarly, spatial augmentation experience might also provide more effective hue shifts according to the types of color-blindness, especially when desaturating the background.

CONCLUSIONS AND FUTURE WORK

The goal of this design project is to create more user-friendly wayfinding solution for pedestrians empowered by emerging technologies such as spatial augmentation and artificial intelligence. Part I discusses the problem spaces in the current wayfinding experience. To identify the design problem, I reframed the definition of wayfinding as an exploratory movement with semantic information of an area in chapter 1. Then, through the case studies, I pulled three design opportunities for the new wayfinding solution in chapter 2. I assumed that it should be able to provide an integrated semantic information platform to its users and foster their confidence in wayfinding experiences.

Part II talks about the technological trajectory in the near future, which ultimately indicates the possibility of out-of-screen experience. While the project examples introduced in chapter 3 show the feasibility of interacting with virtual information in the real space, chapter 4 points out the constraints of the spatial augmentation technology which is the critical factor to consider for its feasibility.

Part III shows how *Reactive Urban Space* is designed through the thorough design process. Chapter 5 describes the entire research methods I used including exploratory research, participatory design workshop, and concept evaluation and the key takeaways from each step. After synthesizing, I concluded that using visual metaphors from nature might help users understand the meaning of the augmented information without using texts. However, the results of the concept evaluation indicate that focusing on color and form factors of organic textures and combining them with universal symbols. Based on the design research, I introduced the final concept of *Reactive Urban Space - BIOPHILIA* in chapter 6 and suggested four design recommendations based on the existing design principles of 2D imagery in chapter 7.

The biggest challenge that *BIOPHILIA* is facing is the limitation of real-time 3D rendering and depth perception technology. It is hard to forecast when the full-extent spatial augmentation experience will be introduced in the market. That being said, the working prototype showed the possibility of the usefulness and the long-term value of *BIOPHILIA*. The next goal of this project is to build a more sophisticated prototype using scale models and façade projection and to suggest design guidelines for better accessibility including physical disability and temporary disability.

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APPENDIX

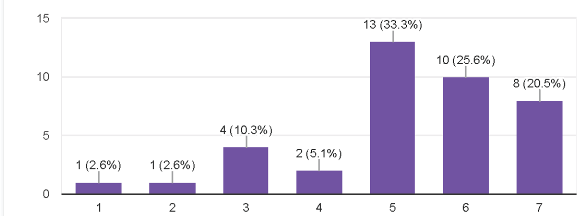
APPENDIX A | Online Survey Result

Wayfinding Behavior

39 responses

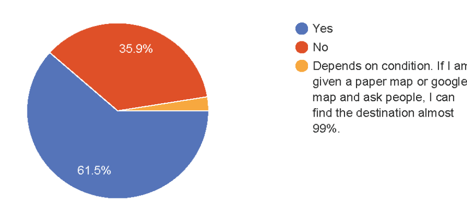
1. How confident are you in reading and understanding information in maps?

39 responses



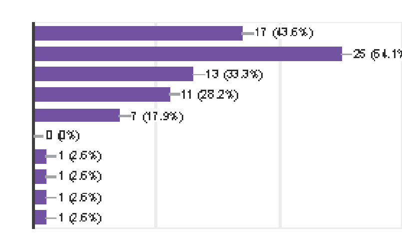
1-1. Is it easy for you to find the destination by its street address?

39 responses



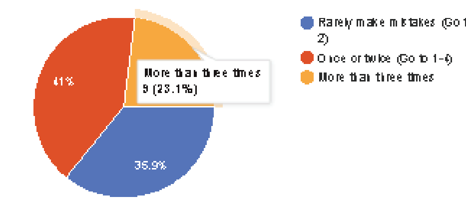
1-2. What is the hardest part of reading maps? (Select all that apply)

39 responses



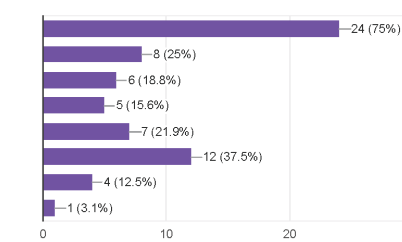
1-3. In average, how often do you get off the route during on-foot navigation?

39 responses



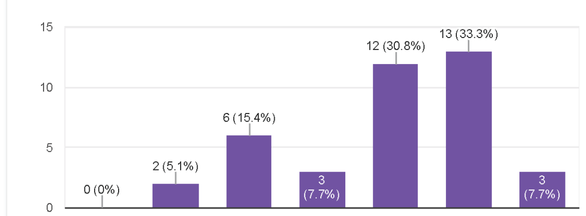
1-4. In which step do you make mistakes the most while navigating? (Select all that apply)

32 responses



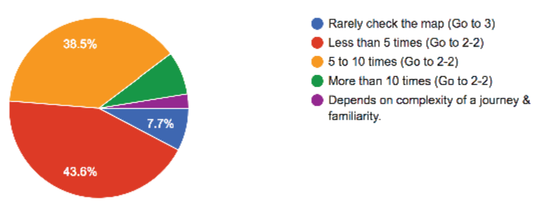
2. How confident are you in finding the right direction in a city?

39 responses



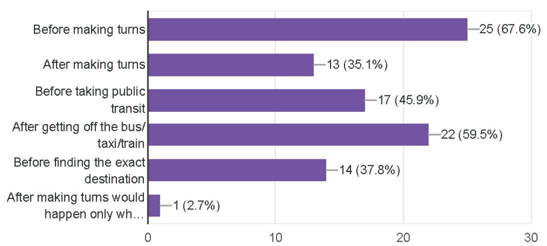
2-1. In average, how often do you check the map to verify the direction?

39 responses



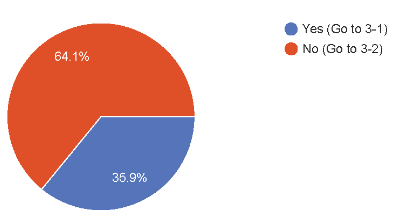
2-2. When exactly do you verify where you are? (Select all that apply)

37 responses



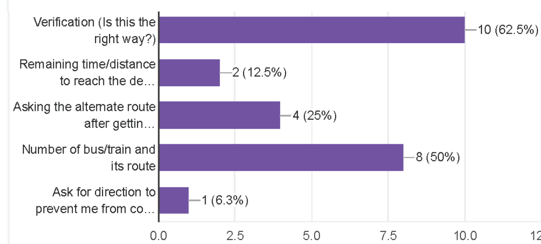
3. Do you tend to ask someone for directions?

39 responses



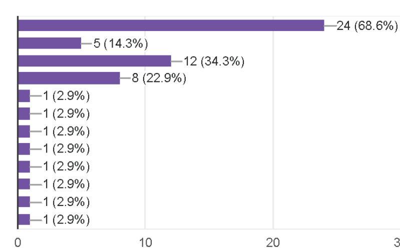
3-1. What kind of information do you ask people? (Select all that apply)

16 responses



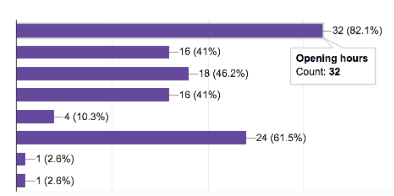
3-2. What makes you hesitate to ask people? (Select all that apply)

35 responses



4. What kind of information do you need/search for your destination? (Select all that apply)

39 responses



APPENDIX

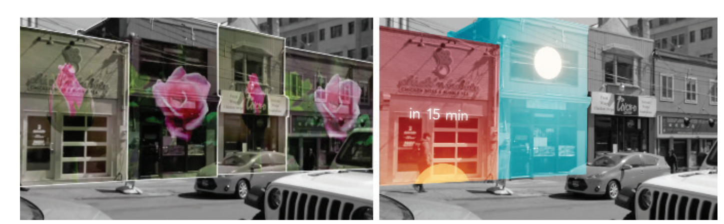
APPENDIX B | Video Prototype Iterations

C-1. Traffic/Safety/Road Closure/Accident

C-2. Wifi signals

C-3. Busyness

C-4. Destination/Bus stop/Store Inventory



C-5. Opening hours

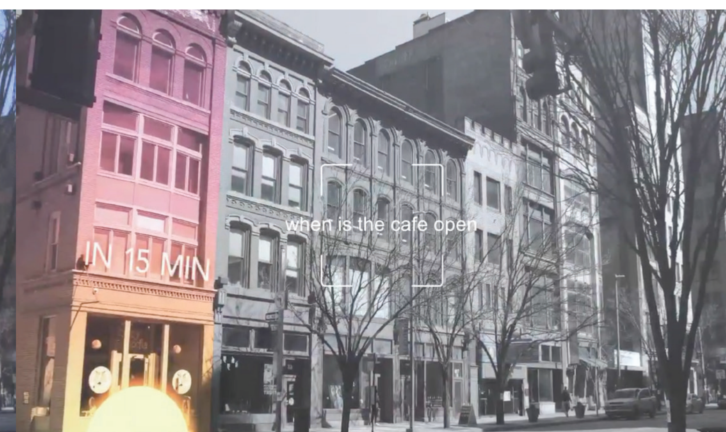
C-6. Ratings/Average Price

APPENDIX C | Working Prototype Screenshots

D-1. Gaze & Speech Interaction

D-2. Destination & Entrance

D-3. Ratings



D-4. Opening Hours

D-5. Busyness

D-6. Wifi Signals


DO NOT ENTER
CHICKEN BITES & BUBBLE TEA
in 15 min
OISHI
274
151

APPENDIX E IRB Study Approvals

Carnegie Mellon University

APPROVAL OF SUBMISSION

December 5, 2017

Type of Review:	Initial Study
Title of Study:	Design with Constraints: Interaction Design Principle for Augmented Reality Experience
Investigator: Study Team Members:	Nurie Jeong Peter Scupelli
IRB ID:	STUDY2017_00000408: Design with Constraints: Interaction Design Principle for Augmented Reality Experience
Funding:	None

The Carnegie Mellon University Institutional Review Board (IRB) has reviewed and granted **APPROVAL under EXPEDITED REVIEW on 12/5/2017 per 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on 12/4/2018.**

If continuing review approval is not granted before the expiration date of **12/4/2018,** approval of this study expires on that date, unless suspended or terminated earlier by action of the IRB. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Unanticipated problems and adverse events must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct of research and conflict of interest.

Sincerely,

John Zimmerman
IRB Chair

Carnegie Mellon University

APPROVAL OF SUBMISSION

March 14, 2018

Type of Review:	Initial Study
Title of Study:	Design for Semantic Navigation powered by Augmented Reality
Investigator: Study Team Members:	Nurie Jeong Peter Scupelli
IRB ID:	STUDY2018_00000060: Design for Semantic Navigation powered by Augmented Reality
Funding:	None

The Carnegie Mellon University Institutional Review Board (IRB) has reviewed and granted **APPROVAL under EXPEDITED REVIEW on 3/14/2018 per 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on 3/13/2019.**

If continuing review approval is not granted before the expiration date of **3/13/2019,** approval of this study expires on that date, unless suspended or terminated earlier by action of the IRB. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Unanticipated problems and adverse events must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct of research and conflict of interest.

Sincerely,

John Zimmerman
IRB Chair

Carnegie Mellon University

APPROVAL OF SUBMISSION

April 18, 2018

Type of Review:	Initial Study
Title of Study:	Evaluative Research: Spatial Augmentation
Investigator: Study Team Members:	Nurie Jeong Peter Scupelli
IRB ID:	STUDY2018_00000100: Evaluative Research: Spatial Augmentation
Funding:	None

The Carnegie Mellon University Institutional Review Board (IRB) has reviewed and granted **APPROVAL under EXPEDITED REVIEW on 4/18/2018 per 45 CFR 46.110 (7) and 21 CFR 56.110. This APPROVAL expires on 4/17/2019.**

If continuing review approval is not granted before the expiration date of **4/17/2019,** approval of this study expires on that date, unless suspended or terminated earlier by action of the IRB. **Note that submitting for continuing review in a timely manner is the responsibility of the PI.**

Unanticipated problems and adverse events must be reported to the IRB within three (3) working days. Any additional modifications to this research protocol or advertising materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation.

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Sincerely,

John Zimmerman
IRB Chair