MOBILE FOCUS + CONTEXT: EXPLORING THE COMBINATION OF LARGE OVERVIEWS WITH HIGH-RESOLUTION DETAILS IN DYNAMIC, MOBILE WORK ENVIRONMENTS

by

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DEDICATION PAGE

Everything in the universe is within you.
Ask all from yourself.

~Rumi, 1759 Divan-e Shams

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ABSTRACT

This thesis explores the concept of Mobile Focus + Context (mF+C)- using a phone to view details of content shown on a mobile projected display. A mobile phone and portable projector can be combined to give a truly mobile information display system. After defining the characteristics of an ideal mF+C system we present a limited prototype using off-the-shelf hardware, and define ways to address the limited projection size. Next we present a mockup that creates the user experience of a fully-featured mF+C system, used as an experimental apparatus. We identify three candidate interaction techniques for linking the mobile phone (focus) and the projector (context) displays that we compare in a user study: Immersive (IMS), where the phone works as a lens controlled by moving it relative to the projection, Side-by-Side (SBS) where the detail on the phone is highlighted on the context, and the user pans the focus by swiping, and Swipe (SWP) where the user simultaneously pans the projected context and the focus by swiping. We find that SWP took longer and was least preferred of the three techniques to perform a range of tasks involving maps and electronic diagrams. IMS and SBS were equally preferred, and performed comparably in terms of time and accuracy. IMS involved fewer shifts in attention between focus and context, and more overall time spent looking at the focus screen, and this is correlated with a robustness to degradation in context image quality, which may be useful in noisy and dynamic work environments.

LIST OF ABBREVIATIONS USED

mF+C	Mobile Focus + Context
AR	Augmented Reality
VR	Virtual Reality
F+C	Focus + Context
O+D	Overview plus Detail
OSC	Open Sound Control
QR	Quick Response
FoV	Field of View
MERL	Mitsubishi Electric Research Laboratories
AMT	Aircraft Maintenance Technicians
CAA	Civil Aviation Authority
WI	Work Instruction
ppi	Pixels per Inch
POI	Points of Interests
KLM	Keystroke-Level Model

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CHAPTER 1 INTRODUCTION

We are in the information age. This period has seen a shift from analog systems (e.g. drawing by hand) to digital systems (e.g. plotting by computer using 3d software), and the creation of digital infrastructures (e.g. data communication via Bluetooth and Wi-Fi). People have come to expect just-in-time information access, for instance, information about their surroundings [14], what to eat [29], or available flight tickets [57].

Accessing high level information often leads to a desire to drill down into details. For example, by using a web search engine, we can easily find that "*The Citadel is a famous historic site in Halifax*", but as a tourist, we may then want answers to the following questions:

- *How do I get there?*
- *What is the best time to visit the Citadel?*
- *How much is the ticket?*
- *Can I take photos, or record video?*
- *Are there any restaurants nearby?*
- *What will the weather be like when I visit?*

We can find most of this information piecemeal on the internet, but having all the answers on an interactive portable map may be useful for the tourist, such as highlighting points of interest and suggested walking routes, and providing links to information about nearby services. This raises questions, such as how large and information dense the map should be, whether it should be purely digital or a mix of digital and physical, and how additional details should be linked.

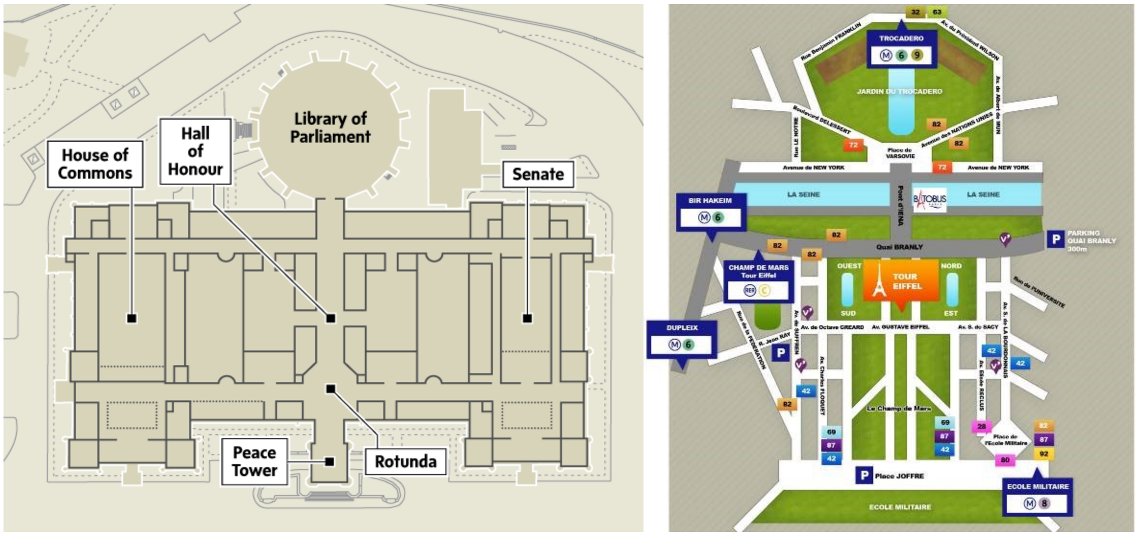

Figure 1 Visitor's map: Parliament of Canada (left) Eifel tower (right)

An interactive historical site map is just one example of how a large, portable information display could assist us in our everyday life. There are many examples in the workplace also. For example, technicians, mechanics, and engineers often work with technical diagrams to find component locations, read part numbers, and identify items in need of repair. They work with complex plots in very fine detail that employ a range of visual markings and attributes, such as numbers, shapes, sizes and colors. They can review, search, and mark up such documents many times over the course of a job to assist in decision making and verification. As human computer interaction researchers, we want to identify and explore approaches that will facilitate doing this on the job site.

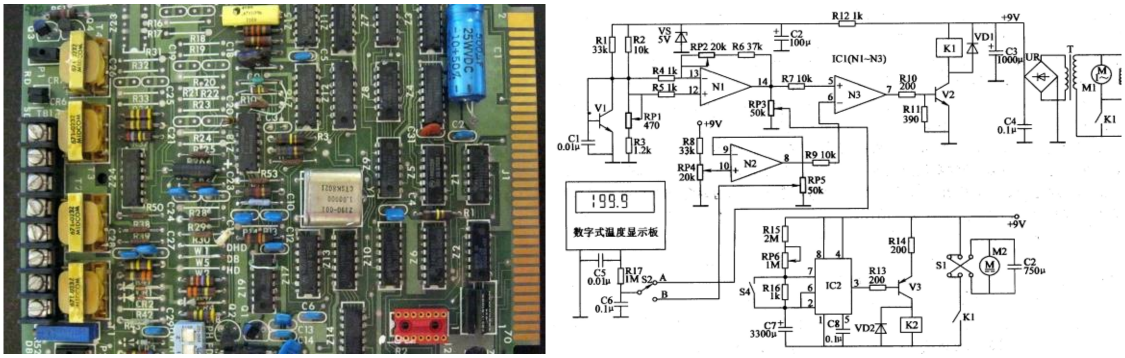

Figure 2 Electronic board picture (left) Electronic board diagram (right)

In the aerospace industry, a Work Instruction (WI) is a guide for assembly or maintaining aircraft elements. It shows how to assemble different parts and how technicians must perform their tasks [47]. Aircraft Maintenance Technicians (AMTs) are working under limited time, stressful conditions and minimal feedback [32]. Human errors in aerospace maintenance have an impact on operations [10].

Figure 3 Aircraft technicians need documents during maintenance, documents are available on their desk (left) or they keep in their hands when he is sitting in the engine (right)

Ott et al. in 1995 [39] (as cited in [36]) reported that aircraft technicians spent 45% of their work time reading instructions and operation manuals. According to the recent Aircraft Maintenance Risk Incident analysis [45] and human factors in aircraft maintenance and inspection [8] provided by the Civil Aviation Authority (CAA[1]), computer systems are an essential tool on the job to counter limitations in human working memory. Digital information is also more easily shared, maintained, and archived across the organization than information captured on paper.

In the information age, many devices have been invented to make a transition from analog data to digital data. These days, finding information on electronic devices, such as desktops, laptops, tablets, and mobile phones is often easier and more convenient than using printed books, journals, and guidelines. We can store a huge amount of information on a single device and carry it everywhere. Identifying the appropriate medium (smartphone, tablet, workstation, etc.) to access this information must take many factors into account, including the work location, the time available, the desired level of accuracy, and the work activity itself. For example, a mobile phone or a tablet is portable and has a touch screen and a high resolution display which is sufficient for operating as a data provider anywhere. However, the size of the display may not be large enough to have an

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[1] www.caa.co.uk

overview and the information details displayed simultaneously. Returning to the Citadel example, one might have a small overview map of the Citadel on one screen but need to navigate away from the map to read information about nearby restaurants. Workstations and kiosks offer larger information displays but sacrifice portability. In the aerospace industry this carries large costs as mechanics need to leave the job site to access information, and then print or otherwise record a hopefully sufficient subset of the information needed to do their job. Portable projectors offer a large, portable information display, but projection is affected by environmental factors such as light or the type of surface that the picture is projected on, and such projectors typically have a lower resolution, so the provided information may not be as clear as physical displays.

In a Mobile Focus + Context (mF+C) system, a Focus device to show a high resolution image of the data in detail is a mobile phone, and the Context device providing an overview of content is a portable projected screen.

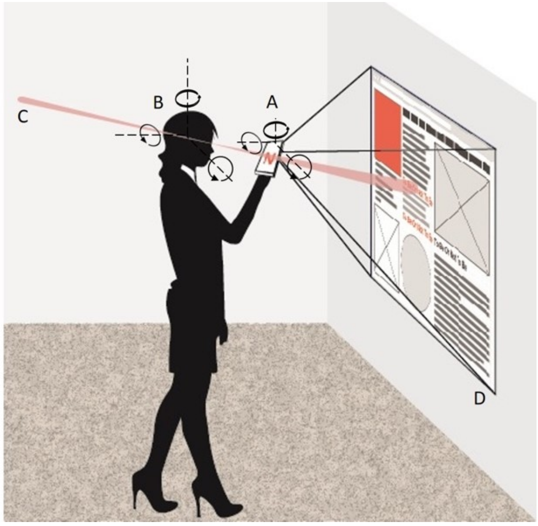

Figure 4 An mF+C system: a) Mobile phone position and orientation b) User head position and orientation c) Line of vision d) Projected screen by embedded projector

The concept of an mF+C system is a mobile phone being operated as a lens to get more details of the provided content on a large display. While the mobile phone is portable, the user will be able to work anywhere. A combination of the mobile phone and portable projection could be used to give a truly mobile information display. For example, our tourist could access a large interactive map by projecting against the wall of the Citadel, and our mechanic could explore a schematic from inside or outside the fuselage.

To implement an mF+C system, first we need a projected image on a surface. Due to environmental conditions (e.g., non-planar, non-uniform surfaces, variable lighting) and projector limitations, the picture may be dark or unclear, texts may not be legible, shapes may be unrecognizable, and colors may not be distinguishable. In many cases the user may only see a rather vague overview of the image. However, the user can use the phone to access details related to the projected image. The high-level goal of the work presented in this thesis was to explore cases where an mF+C system could be useful and to identify factors that need to be considered when designing and implementing an mF+C system.

1.1 Contributions

In this thesis, we define the "ideal" mF+C system hardware as a self-tracking handheld device with an embedded projector on the back, and a wide angle camera in the front to track the user's relative viewing angle. Such a system was not available up to the time of writing. We iteratively experimented with off-the-shelf hardware components and software APIs, culminating in a limited proof of concept prototype and a set of hardware requirements for an ideal system. As a result of informal testing we also identified a number of approaches to address the prototype's main limitation of small projection size. We then implemented an additional mockup as an experimental apparatus, using tracking sensors and a stationary projector, to evaluate the user experience of an mF+C system.

Through a consideration of prior work, we identified three potential methods for linking detail on the handheld screen with the projected context: Immersive (IMS), where the phone works as a lens controlled by moving it relative to the projection, Side-by-Side (SBS) where the detail on the phone is highlighted on the context, and the user pans the focus by swiping, and Swipe (SWP) where the user simultaneously pans the projected context and the focus by swiping. We conducted a comparative evaluation of the three linking techniques with 36 participants, who each performed 14 tasks. We also compared the techniques with a "phone only" approach as a baseline. For the mF+C methods, we introduced two projection conditions: optimal and suboptimal. In optimal, the projection was clear and bright, while in suboptimal, a variety of environmental conditions impacting projection were simulated (spot lighting, wavy surface, etc.); we assigned six tasks to each condition. We derived an even number of tasks involving maps and electronic circuitry, inspired by our tourist and mechanic scenarios, respectively. We found that IMS and SBS performed comparably to phone only in terms of task time and accuracy, while IMS appeared more robust to changes in projection quality. SWP was ranked as the least favored method of mF+C by the participants. Familiarity with content type (map or circuitry) was seen to influence task performance.

To summarize, this research makes the following contributions:

- System contributions:
    - Identified system requirements of an mF+C system
    - Created a limited prototype of an mF+C system using off-the-shelf hardware, and defined modes that address limited projection size.
    - Built a functional mockup using tracking sensors and a stationary projector to create the user experience of interacting with mF+C methods
- Human-centric contributions:
    - Developed three candidate techniques for linking focus and context views in an mF+C system, inspired by prior work.
    - Explored the user experience of mF+C and identified advantages and disadvantages of each linking technique, including how they compensate for poor context visibility due to projection on non-planar and/or non-uniform surfaces
    - Assessed the impact of familiarity with type of content on performance when using an mF+C system.

1.2 Structure of the thesis

This thesis is divided into seven chapters: Chapter 2 is about information display systems and related works. Chapter 3 explains the Mobile Focus + Context system, which was developed in this project by using three methods of interaction. We also discussed why we need this system. What are the advantages and disadvantages of each method? Which hardware and software are available to make an mF+C, and what we required to create an mF+C system? We will also discuss how the mF+C system could be helpful. Chapter 4 begins with the user study introduction, which will be followed by the study design and procedure. In Chapter 5, we analyze the collected data. The discussion, limitations, and future work will be described in Chapter 6, and Chapter 7 is the conclusion.

CHAPTER 2 RELATED WORK / LITERATURE REVIEW

The first section of this chapter explains the information display systems and their properties. It is important to know what features might be included in a handheld information display device. We also will review the related works including Focus + Context Systems, Overview + Detail Systems and implemented interaction techniques by using the earliest and the most recent methods. We will also review some of the device tracking systems and techniques.

2.1 Information Display

Information displays can provide static information, for instance, to show the side effects of drugs in a hospital, or dynamic (real-time) information, such as stock price boards, scoreboards in sports complexes and train station boards. These systems are available in different places, such as airports, museums, offices or banks. Each system has unique properties, but some of the properties are common. In this section, we describe some important properties of information displays, which are also useful in a handheld device that works as a portable information provider. All these attributes were considered to identify the properties of an mF+C system. We also applied some of these factors in our developed mockup for the user study.

Figure 5 Information displays. Left: at an airport. Right: at a hospital.

2.1.1 Portability

All the systems divide into two forms of portability (see Table 1). They are either fixed or portable. The portable devices are those that are anticipated to be moving during normal usage.

Portability	
Fixed	Portable
Large screen in the airport, museums	Laptop, mobile, tablet

Table 1 Information display properties: portability

Devices such as mobile phones, laptops, and tablets with different screen sizes are portable, and if a large screen is required, we can connect them to a video projector. All devices are small and can be put in a backpack. The fixed systems are typically not movable or cannot be relocated easily. For example, a large screen at the airport or museum is in a fixed location. As well, a system with a desktop computer that is connected to a 40" LCD screen is movable, but it is not easy to carry it everywhere. Due to an mF+C system portability feature, it can be used anywhere without any additional devices.

2.1.2 Screen size

Screen Size					
4" - 5.5"	6.5"	7" - 13"	13" – 18"	18" – 27"	+27"
Phone	Phablet	Tablet Netbook	Laptop	Desktop Video Projector	All-in-one PC LCD Large Dot Matrix Video Projector

Table 2 Information display properties: screen size

Table 2 shows the variety of screen sizes in an information display. A display with a smaller screen than a laptop (<18") is usually portable. All mobile phones, tablets, phablets, and laptops are common devices with small screen. The displays greater than ~18" are usually used for stationary devices. All-in-one PCs, LCDs (e.g. monitors, TVs), Dot Matrix screens are used in systems that are less portable by a person. Video projectors are portable devices that are available in different sizes from pocket size to stationary size, but even the pocket size or Pico projectors can provide a large screen with the same size as a desktop or a stationary display greater than 18". In an mF+C, it is necessary to have a resizable overview, which can fit on any surface.

2.1.3 Resolution

The quality of screen has an impact on the details of the displayed pictures, texts or diagrams. A picture on a 100” Dot Matrix screen (369 * 208 pixels) has lower quality than the same picture on a 100” video projector screen (1024 * 576 pixels). It is because the pixels density on the Dot Matrix screen (4 ppi) is three times less than a video projector (12 ppi). These days, LCDs are available with Ultra-HD (4K, 8K with 44-88 ppi) quality, which can provide a high-resolution picture and text on screens with size of up to 100”.

Resolution		
Low resolution	High resolution	Mixed
LED Dot screen Video projectors	LCD LED	LCD + Projector LCD + Dot matrix
Score board Advertisement billboards	TV, Tabletops, Information desks	Museums, Art galleries

Table 3 Information display properties: resolution

Several types of displays are categorized in Table 3 based on the resolution. Information display systems could be made with two different screen qualities (e.g. LED Video Screens by AVL Systems Ireland[2], focus + context by Baudisch et al. [3], see Figure 6). These provide a high-resolution screen, showing detail, embedded in a low-resolution screen providing an overview.

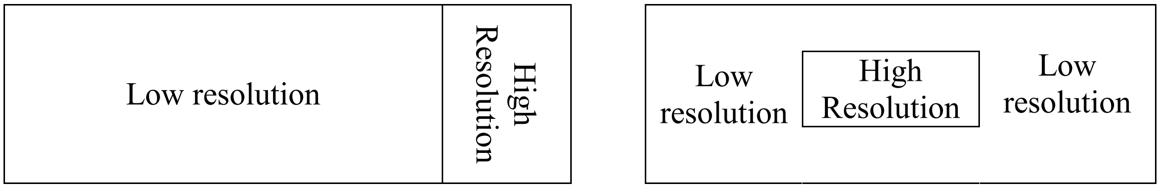

Figure 6 Type of displays with high-resolution combined with low-resolution screens. Left: AVL Systems. Right: Focus+context [2].

A high-resolution detail provider is an important part of an mF+C system.

2.1.4 Availability

The large screen information display system which uses an LCD needs a stand or should be installed in a fixed location (e.g. on the wall). In addition, a covered location is needed in some weather conditions (e.g. a rainy day), and the installation location should be at

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[2] www.avl.ie/products/led-video-screens

least the same size as the screen. Whereas a phone, tablet and laptop could be available everywhere, they have small screens compared to a screen provided by a video projector.

Availability	
Fixed location	Everywhere
LCD, LED	Video Projector, Mobile Phone, Tablet

Table 4 Information display properties: availability

A video projector can project on many types of surfaces, even on a non-planar or a colorful surface. There is no minimum limitation for the surface size, and if a wall is not available then the data can be projected onto the floor or ceiling. Since projectors can operate using rechargeable batteries, they can provide a large screen almost everywhere.

2.1.5 Number of users that can use the system concurrently

Due to the small size of the screen and limited physical space around the display, devices such as mobile phones, tablets and laptops are typically single user devices.

Number of users that can use the system concurrently	
Single	Multiple
Mobile Phone, Tablet	Tabletop, Video Projector

Table 5 Information display properties: number of users that can use the system concurrently

Table 5 shows several devices for a single user and multiple user categories. There could be applications that work on mobile phones that let more than one user work on that small screen, but it is not a common use of a mobile phone. Moreover, there might be large displays (e.g. information kiosks) that can support one user at time, but that could be because the application does not support multiple users, or the system only has one-way inputs (mouse only, no touch screen). However, large display systems such as tabletops and systems that use a video projector as a screen can offer working areas for more than one user (Figure 7). An mF+C system can also make it possible to use a large overview by more than one user.

Figure 7 Diamond Touch Tabletop in MERL[3]

2.1.6 Precision

Tracking the precision of user interaction is a challenge. For example, on a touch screen display, if the touch area is not calibrated with the application layout, using the system is not convenient, and the user might not get good feedback. In a 2D system, the user's position and orientation do not have an impact on what a user sees as content, but in 3D systems, the user's head position and orientation have a direct impact on what part of the objects are in the user's view on the screen. In an mF+C system, the amount of precision is related to how the detail provider is coupled with the overview.

2.1.7 Application of portable information system

A portable information display system that uses a mobile phone and a projector is applicable for a variety of tasks in different conditions and locations. A mechanic or technician who needs to look at technical designs at the worksite could use this system to project the content anywhere; then they can see a big picture of the design and use the mobile device to get more details. A tour guide can help tourists by showing a 3D model of famous and historic buildings on the mobile device. While a city map is projected on the floor, she can use the phone to show the nearby services. A portable information display system is also useful for teamwork. A group of students, who want to discuss design of a prototype, can project the 2D model on a wall and see details in 3D view on the phone.

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[3] Mitsubishi Electric Research Laboratories (MERL) www.merl.com

People who deal with high amounts of detailed images are one of the expected groups of an mF+C system users. This is because the high amount of details in the images make it difficult for them to have a clear view of these details on a phone screen.

2.2 Large displays

Large displays are physical screens or projected content on a large surface. The physical screens are less portable, more expensive and cannot be installed everywhere. However, in the last decade, the dimensions, weight and price of the high-resolution projectors have decreased. Simon and Manhannan [48] report that users performed MS Excel and Excel/Word multi-tasks in less time on 21” diagonal screen to compare with 15”, 17” and 19” screens, using the same PC and regular input devices (mouse, keyboard). Czerwinski et al. [11,12] examined user performance benefits of large displays. They compared the productivity of multi-application computer tasks on the same PC with common input devices (mouse, keyboard). They used a 15” LCD screen (1024 * 768) and 42” wide curve screen, made by three projectors. The display made by projectors was three times wider but the same height (3072 * 768), like a 15” LCD monitor. They found that users worked faster on the large display than the small screen. Participants whose computers had large displays could also memorize more phone numbers than the ones with small display computers. In our user study when we used a large projected picture as an overview, users could memorize the names of the locations and recall them for completing the requested tasks.

2.3 Focus + Context Systems

Focus + Context is a technique to reduce the spatial separation when the focus and context are merged in the same view. Fisheye [19] is a technique where an overview of data is available and a focus view with detail exists on the context. However, there is a trade-off between detail size and context information. Fisheye might be not a useful technique for very large sized documents (e.g. 3m x 2m with 150dpi – 17717x 5906 px) on mobile phone screens (3.5” to 5.5” – Full HD 1920x1080) if the overview does not provide useful information. To overcome this problem, we need a larger overview screen that surrounds the focus view.

The Focus + Context (F+C) screen system [3] was developed in 2000 at XEROX PARC by Baudisch et al. The system used a low-resolution video projector to display a big picture of a map on a large screen and an 18-inch high-resolution LCD monitor, which was embedded in the screen as focus device. Displaying details of a map with high-resolution in the focus section was one of the experiments of this implementation. The original F+C system (Figure 8) was a combination of a low-resolution and high-resolution screen. They adopted some applications, such as Adobe Illustrator, video conferencing and a first person shooter game to present how the system could be useful. They set up the system in a lab and allowed other researchers to use their system. Because of the large space for drawings, they received positive feedback from groups who worked on hardware design and people who were working on graphic content, such as posters, sketches, and the web. From the feedback, they found that the system was very useful for supporting large documents, and there was “lots of space” to work.

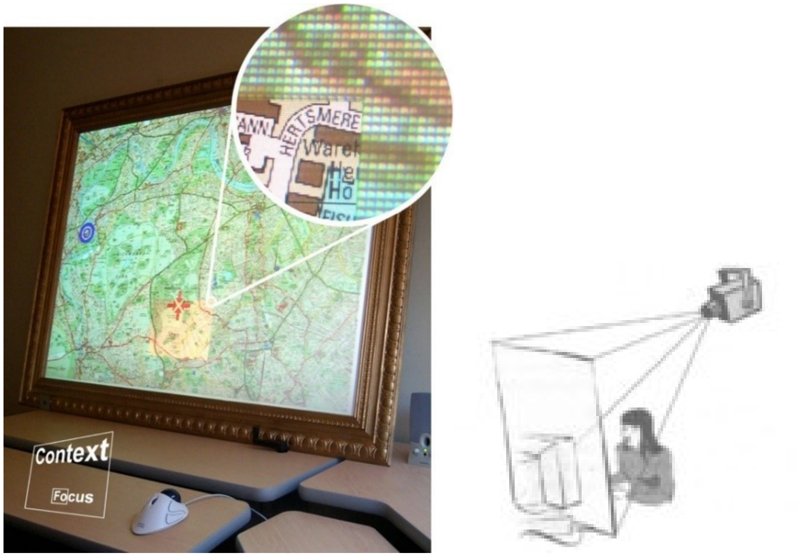


Figure 8 Focus plus Context

They also had some feedback from people who were not interested in that system, and they were basically dealing with texts in their professions. The system needs less space compared to the other large displays, such as tiled projection or large hi-res displays.

Due to the embedded screen on a surface, the system was not portable. One problem that we faced when using this system was that as far as the focus display is embedded in the context surface, the user needs to sit very close to the context screen to see the details in focus. We considered this problem in our research.

Figure 9 F+C on Pocket PC by Lank

There are several F+C mobile and desktop applications. In 2004 Lank et al. [31] developed F+C sketching system on a Pocket PC (Figure 9). They developed a sketch application on a Compaq IPAQ. They asked participants to write or print text and draw a diagram with scrolling and fisheye interfaces using a touchscreen stylus. The users were free to switch between interfaces. The users were able to draw on focus device when seeing the context on the outside of the focus section. As a result, they concluded that users prefer the fisheye interface rather than scrolling in both tasks. The advantage of this system was portability, and it was available everywhere. In our research, we are aware of portability of focus and context.

Figure 10 F+C with marker by Flider and Bailey

Flider and Bailey [18] combined a projected screen and a Wacom Cintiq graphics display tablet on a desk a few feet away from the wall. The tablet had a high-resolution (1280 * 1024) and large (18”) screen. A red rectangle was available on the context screen as a reference for a designer to know the location of the context on the tablet (Figure 10). A 3D

Connexion Cad mouse was used to control the context position or reference frame. They evaluated users' performance, goal error, and satisfaction in two identified methods. The methods were moving content in the same direction of the 3D mouse movement (Paper mapping), or in the opposite direction of 3D mouse movement (Scroll mapping). As a result, they found that most of the users' attention was on the context screen when controlling the display. The users also performed Scroll mapping 25% faster, with 70% less error in panning and 41% less error in zooming compared to Paper mapping. Overall users were more satisfied with Scroll mapping in comparison with Paper mapping. The two separated screens that are not on the same plans and moving pointer are considered in our research.

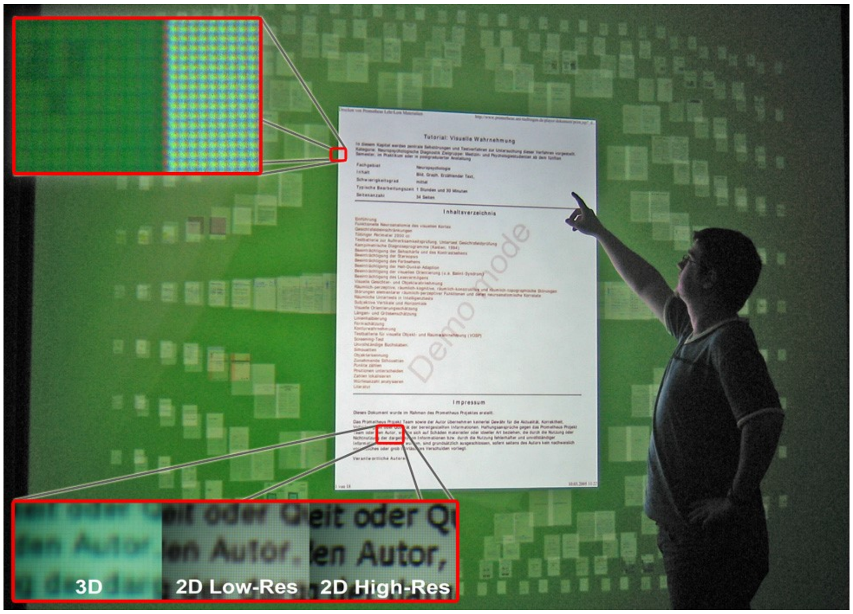


Figure 11 A large 2D + 3D Focus + Context Screen developed by Ebert

Ebert et al. [16] designed a F+C screen to show high-resolution data on a 2D screen when it is in a big 3D context (Figure 11). The system was implemented by two 3D projectors to provide a wall-size screen (2.9m x 2.3m) as a context. There was a Full HD (1920 * 1080) 2D projector to provide a high-resolution screen (0.9m x 1.3m) as a focus, which has 3.5, times higher resolution than the context. A user study was conducted to evaluate the reading time and error. The results show that average reading time on 2D-Low-res (1.4 word/sec) was about three times faster than 3D mode (0.5 words/sec); however, in 2D High-res, the average time was 1.9 words/sec. While the average error of reading tasks was

1.26 in 3D mode, it dropped to 0.65 in 2D Low-res and zero in 2D High-res. The results show that high-resolution 2D focus area improved the time and decreased the error rate. The system was using multiple projectors; however, installing and calibrating three video projectors lead to a less portable system and also requires a bright planar surface. The size of context, quality of focus, and some properties of projection (e.g. planar surface) are considered in our research.

Figure 12 Smart Flashlight

Dancu et al. [13] developed the Smart Flashlight. They used a combination of a mobile phone and a Pico-projector to create a bike-mounted projector system to show a large picture of the map in front of the cyclist. They compared the mounted smartphone display with the projected display at night, and evaluated how visuo-spatial parameters affect the interface design for interaction in motion. They used an LG smartphone with 4.7” display and a Brookstone pocket projector, which was connected to the phone with an MHL adapter alongside the Viking application. They also attached a GoPro camera to the helmet to record a video of the journey. Sixteen cyclists conducted the experiment by riding in four different routes at night to compare map navigation using smartphone display and a portable projector. 69% of participants found that using a projector was easier and more helpful than a mobile phone. The report also shows that the projector-based system had a higher roadand traffic visibility, and 75% of participants reported that the projector-based system was safer. Participants were interested in the large map by the projector because the street names and map route were clear. For the period that they were using the phone display, some participants missed the turns because of the small display, and they forgot to look at it. They reported that they had less safety concerns when they were using the projected map compared to the phone map because the projected map was in a better view angle, which allows them to keep their eyes on the road. All participants said that the projection was bright and clear enough for navigation. Projector location, brightness, distance from the surface, visibility of data on a small screen vs. a large screen, and portability were the parameters that we considered in our research.

2.4 Off-screen locations techniques

Context-aware techniques have been applied in many visualization applications. In 2003, Baudisch and Rosenholtz introduced Halo[4], as an off-screen spots visualization (Figure 13).

Figure 13 Halo Technique

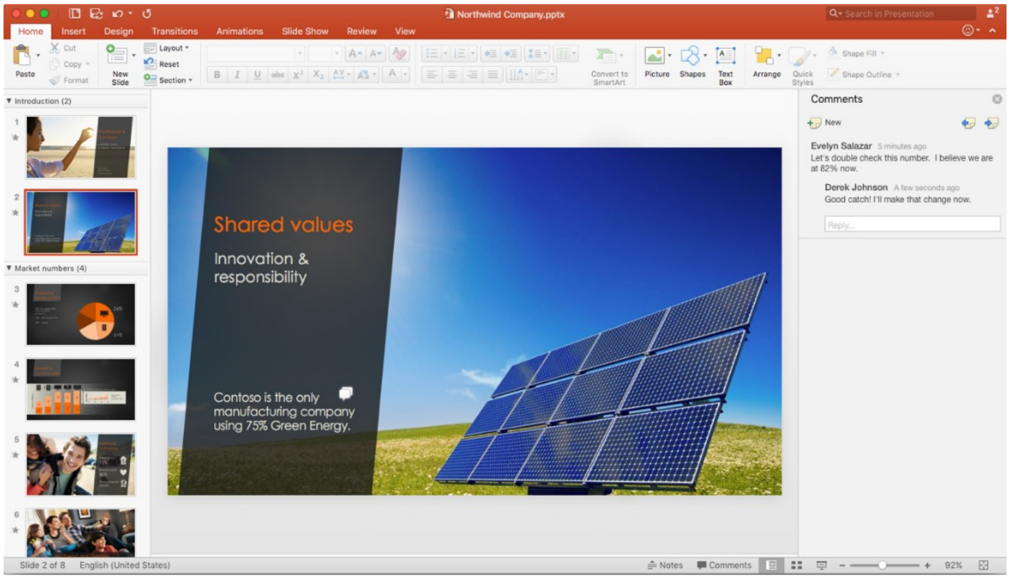
Figure 14 Wedge Technique

Halo extends screen space virtually by adding some circle markers around the screen. The circles sizes and positions are related to the distance of the targets that are not visible on the screen. A user study was conducted to compare Halo with the arrow-based visualization technique by using a map application on an iPAQ Pocket PC and 12 participants. Halo was 16%-33% faster than the Arrow interface and had a higher subjective satisfaction. Halo is considered as one of the techniques to overcome display limitations of the small screens, which is also considered in our research. Gustafson et al. [23] presented

Wedge (Figure 14) as a visualization technique that resolves the multiple overlapped arcs problem in Halo and also shows the direction to and the distance from the off-screen locations. They found that while the targets were in the same direction, the number of arcs increased, so there was a significant clutter of merged arcs that reduced the strength of Halo. In Wedge, isosceles triangles are used instead of circles for a better representation of the target's location. The orientation of triangles solved the overlapping problem in Halo. A user study was done by 18 participants using a simulated PDA on a desktop computer to compare Wedge and Halo. The results showed that Wedge was significantly more accurate than Halo, and the effectiveness was stronger in corners. To overcome the display limitations, we considered using a single portable device with visual and interactive pointers that are related to the current user's point of focus in the developed mockup

2.5 Overview + Detail Systems

To display details of a big picture, Overview + Detail (O+D) is one of the methods. A good example of this method is Microsoft PowerPoint (Figure 15). The side panel contains some thumbnails on the left side of the application. By clicking on each thumbnail, the large slide with details of information will be shown.



Shared values

Innovation & responsibility

Contoso is the only manufacturing company using 75% Green Energy.

Evelyn Salazar 5 minutes ago
Let's double check this number. I believe we are at 82% now.

Derek Johnson A few seconds ago
Good catch! I'll make that change now.

Figure 15 Microsoft PowerPoint with O+D Side Panel

In the O+D approach, details and context information are displayed in two separate windows or virtual screens [41].

Figure 16 Overview vs. detail on mobile devices. a) Classic interface b) Split-Screen interface c) Resizable interface hidden d) Resizable interface - custom dimensions

Goncalves et al. [21], analyzed the effect of the overview scale on mobile O+D interfaces by using the map application. They used an Android phone with a 3.7” display size and evaluated four different types of interfaces regarding size and location of the overview section on detail. Thirty participants performed three tasks, selecting nearest POIs (selection), finding all highly relevant POIs on the map (explore) and memorizing the two of them, and POIs approximate location (recall). The results show that people prefer to use a resizable and non-overlapped overview on a mobile device. They found that users spend more time on the Explore task in Resizable overview because they have to resize the overview window during the task; however, the amount of error was less in the Resizable interface than other methods. Due to the phone’s screen divided for both overview and detail, the overview section is very small and might not be useful for a large map or technical diagram without any marker. Having two separated windows for focus and context, visual markers on context, focus and context on a single portable device, and optimal focus vs. suboptimal context are considered in our research.

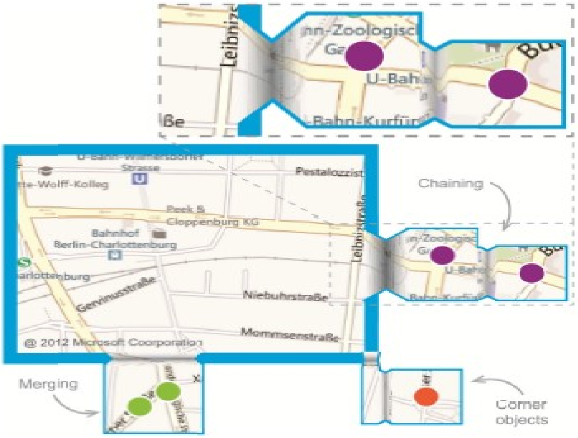


Figure 17 Canyon Technique

An interactive O+D information visualization technique has been presented in Canyon [27], by Ion (Figure 17). The system was implemented by an interactive whiteboard in 3x1.125 m size, with two video projectors and a digital pen. A map application was designed for the user study. A small screen of off-view objects was attach to the Detail section. The space between the details screen and the off-view objects was virtually folded. In Canyon, the overview and detail windows are two separated screens on the same surface that are not overlapped. Sixteen participants were invited to perform four tasks using Canyon and Wedge, which is a well-designed off-screen technique. In the Identification task, Wedge was faster than Canyon; however, in the Movement task, Canyon was more accurate than Wedge. Moreover, the error in Canyon was less than Wedge in Distance and Location tasks. The results also shows Canyon improved the accuracy compared to Wedge. In Canyon, both overview and detail have the same resolution, and they are on the same plane. Therefore, effects of environmental conditions on the overview might have the same effects on the detail section, so in this situation having the data on separated screens has more advantages compared to screens on a same plane. In our research, we considered interacting with a large projected map and separated screens.

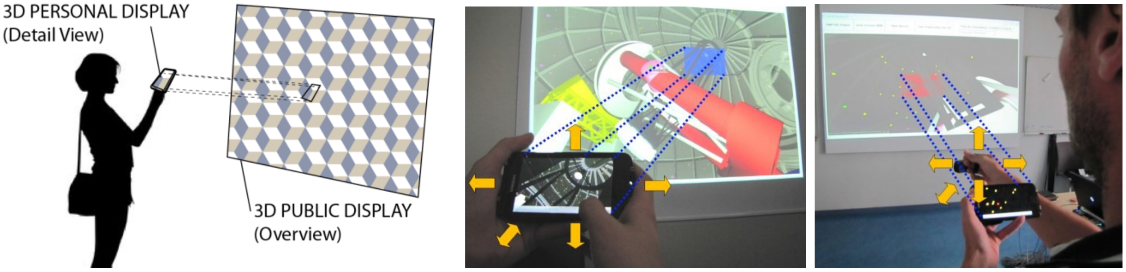


Figure 18   Overview + Detail Interfaces on 3D Public Display

Bergé et al. in [5], explored three different interaction methods using a mobile phone in front of a 3D public display. In the two mid-air navigation techniques, they used a mobile phone position and a user's hand position to find the objects in the Overview section. If a large display was available, the user could use the phone as a details provider. While the mobile phone was portable, by using a portable overview provider, the entire system was also portable. In the user experiment, they asked 12 participants to reach a target, which was randomly placed in a 3D cube. The results showed that the mid-air phone and mid-air hand, which are immersive methods, performed better than the touch technique, which was the base method. They also found that mid-air phone method was easier to use and understand than the mid-air hand method. They reported that the mid-air hand method was the most, and Touchscreen the least, preferred methods. The limitation in this implementation is that the picture, which the user sees on the phone, is just related to the position of the sensors in the tracking system, so if the user is tilting the phone, the picture on the phone will not change. We consider this problem in two ways in our research. First, the picture on the phone is related to the device position and orientation that we evaluated in the first experiment of our research. Second, the data on the phone would be related to the users' head position and orientation with respect to the device's position and orientation. The results also show the methods that are completely based on users' hand movement had a better result than methods with a touch screen, which is considered in our research.

2.6 Augmented/Virtual Reality Systems

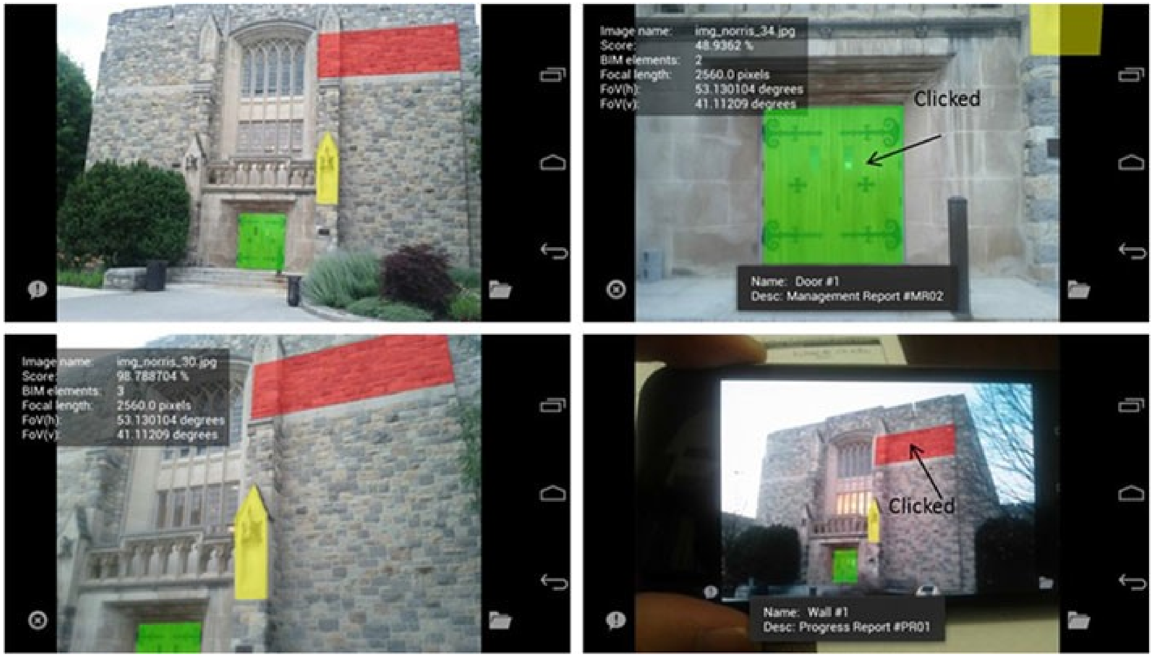


Image name: img_norris_34.jpg
Score: 48.9362 %
BIM elements: 2
Focal length: 2560.0 pixels
FoV(h): 53.130104 degrees
FoV(v): 41.11209 degrees

Name: Door #1
Desc: Management Report #MR02

Image name: img_norris_30.jpg
Score: 98.788704 %
BIM elements: 3
Focal length: 2560.0 pixels
FoV(h): 53.130104 degrees
FoV(v): 41.11209 degrees

Name: Wall #1
Desc: Progress Report #PR01

Figure 19 Mobile Augmented Reality System

Augmented Reality (AR) applications are using vision based techniques to reveal details of the item, which would be highlighted by a marker. A marker could be an overview of a picture or part of a large picture. When the marker is detected by the AR application, the application can execute functions, such as the display details or additional objects. In our research, we examined the AR technique with advantages and disadvantages that will be discussed in the next chapter. Bae et al. [1] developed an application that uses the phone's camera to take a picture of buildings; therefore, by comparing the image with pre-collected site photographs, it can highlight the selected objects on the application. A PC with Intel Core i7 (quad core) processor with an NVIDIA GeForce GTX560 on an Ubuntu OS was used as a server for image processing, and several Android phones were used as clients. The system is portable and does not need any marker or extra sensors, and it is particularly good for large objects. This is not a real-time system and the user needs to take a photo and wait for image processing. As the mobile phones do not have a powerful processor for image processing, the taken picture has to be sent to a server for analyzing, so a network connection is required. To speed up the file transmission, they established a Wi-Fi connection instead of the cellular network. The system is supporting multi-user interaction, but because of the third party service (processing on the server), if many users send a request to the server, it might take a long time to get a result. The results show that the system could apply to a construction site, and it does not need any external tracking sensors, which would be considered in our research. The vision-based tracking in this system is good for the large buildings when small movements (2-10 cm) might not matter, but it is important in our system.

As a virtual reality (VR) system, Hürst and Helder [26], developed a Mobile 3D Graphics and Virtual Reality interaction in which changing data on the device is related to the tablet's orientation.

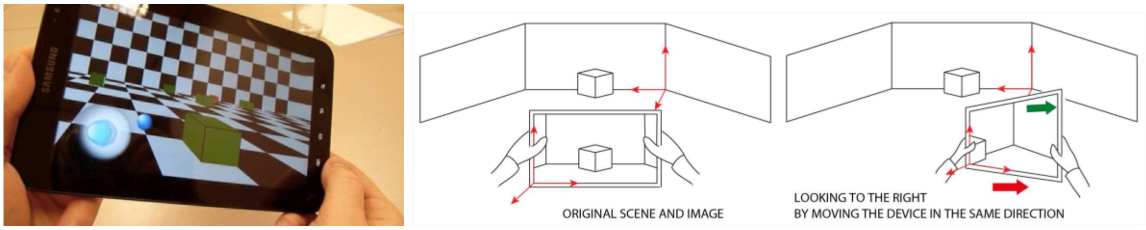


Figure 20 Mobile 3D Graphics and Virtual Reality Interaction

The system provides a 3D model of space in a single device. The system is portable with a high quality screen (1024*600 on the 7" tablet screen, 854 * 480 on the 3.7" phone screen). The application's camera (user's view) orientation is related to the device orientation or can change manually by a joystick button on the interface. Moreover, the camera's position is fixed on the application. While changing the position of the device does not have an effect on the screen's picture, the user's head position and orientation also does not have any effect. They conducted a user study, which included 24 participants. Each participant had to complete three navigation tasks and one selection task. The users had to navigate the blue ball to the target with/without obstacles. In the third task, users were asked to pass obstacles in a slalom-like way to reach the target. The final task required users to select the target by clicking on it on the screen. There are two approaches for controlling the application's camera. In the first approach, the camera is set to follow the blue ball, and in the second approach, the camera is controlled by internal sensors (accelerometer and compass). A mobile phone and a tablet were used to evaluate the system performance, time, and accuracy in each interaction method. The results show that because of the screen size, participants had better performance on a tablet rather than on a mobile phone. Furthermore, they were faster and also made fewer mistakes on most of the tasks when they used the tablet compared to the phone. As they mentioned, each of these tasks were designed to be completed by using two hands: one hand for holding the device, and another hand for interaction (controlling the joystick on the screen or clicking on the target in the selection method). Because of the smaller screen size on the phone than the tablet, using two hands might have an effect a user's performance, which is not measured in the user experiment. Using built-in sensors for orientation tracking let us know how the device's orientation could be involved in an mF+C system.

2.7 Portable Focus + Context System

Weigel et al. [51], used a mobile projector as a Focus device (Figure 21) to provide more details of displayed content, such as the name of streets, the name of buildings and POIs. The details could be available on a Context (Figure 21-left), which is the stationary display. The system could be portable, but the quality of the focus part is not as good as the picture on the mobile screen. However, they believed that their system is a toolkit for developing different applications, so they did not evaluate it.

Figure 21 Combining Mobile Projectors and Stationary Display. (Left) Details of map are projected on a large display. (Right) Mobile projectors provided details outside of the screen.

They found that tracking the position of the projector using external tracking hardware and projector brightness were technical limitations. The light issue is known as an environmental problem. Moreover, we believe that while the details could be projected anywhere (Figure 21-right), the details could be shared for collaboration; however, because the details are visible to everyone, it could jeopardize the privacy in case the user does not want to share with others. It is true that projectors can project anywhere, but as we can see in this implementation, a planar surface is needed to see the details of the focus section.

The details might not be identifiable on a curtain, rug or dark surface. This problem is discussed in our research.

2.8 Projector location

The location of the projector is one of the most important factors in an mF+C system. The projector can be attached to the phone [9,43], mounted on a stable part [13], or put on a head [30,46] or body [34,35,53]. In an mF + C system, a projector must be in a location where the user's shadow does not appear on the projection area. A pocket size or a Pico projector can be installed on the top of the user's head.

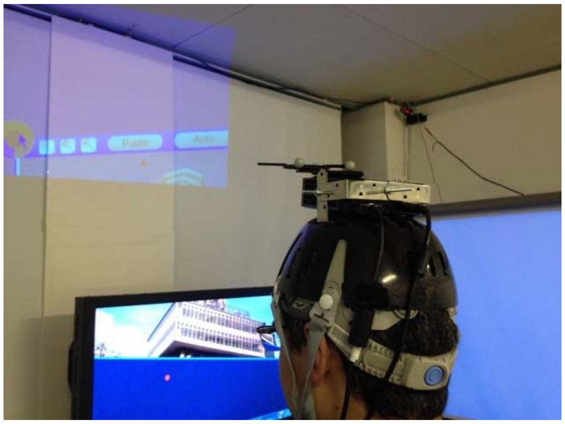


Figure 22 Head-mounted Projector

Chernicharo et al. [7], used an ultra-portable Dell projector on the head (Figure 22) to broaden the content visibility area over the fixed desktop display by projecting content on the surface around the fixed screen. In a user study experience with five participants, the researchers measured the usability of each interaction scenario, such as head-mounted projector + mouse (HeadMouse) with other methods, handheld + mouse (HandMouse), handheld + laser (HandLaser), and head-mounted + laser (HeadLaser). The results showed that HeadMouse was simpler, seamless and more intuitive than other methods. In this study, the shadow, size and weight of the projector were reported as limitations, so we considered these problems in our research. The projector's location and movement were also considered in our project.

In BrainyHand [50], a head-mounted projector displays information on the user's hand, and the attached camera is recording the user's interaction. In the Interactive Dirt [33], McFarlane et al. attached a miniature projector (Dell M109S) to the user's shoulder. A field experiment reviewed methods used for system evaluation. They show the projectors could provide content on different places, such as the body of cars, trees or on the floor. Projecting on several types of materials is considered in our research. Ota et al. [38], evaluate projector location on different parts of the body. While some of the locations had advantages and disadvantages, they reported that projector on the waist had the worst score because the projected area was affected by the movement. The projector on the head allows a user to project in a line of eyesight everywhere, so the user can project on a floor or a ceiling. However, once the user is turning his head to look around, the projection area also will be turned, which makes interaction more difficult. If the focus of interaction was on a specific object on the projection area, there were some solutions such as Sticky Light [22], which is developed by Gunn. In this system, a head mounted camera records the objects, which were in front of the worker, and sends the data to the expert. The expert chooses the working area, draws some lines, and sends added information to the worker. A Pico projector on the hard hat projected the drawing on the objects. The results showed that the system was operating fine in good light conditions but not in the sunlight due to the projector lumens. The system also was not working well in a dark environment, because the camera cannot capture a clear picture.

The projector on the waist is in the opposite direction of the head location. In this situation, the user needs at least one surface in front of their body to project on, or the projector beam direction must be adjustable, so the user can look around the projection area by turning his head without any problems.

2.9 Tracking systems

Tracking the position of a handheld device to move around the screen on a large workspace is an identified challenge. Sensor-Based, Vision-Based and Hybrid tracking techniques [37] are three common systems to find the position and orientation of the device, also Zhou [52] reviewed these tracking systems. Table 6 is based on Zhou's reviews.

Tracking system	**Cons**	**Example**
Sensor-based	Absorption environmental impact (magnetic field), Short range, Position tracking is expensive	Electromagnetic, GPS, Gyroscope
Vision-based	Short range, Heavy process, Absorption environmental impact (light, Sun IR)	VGA Camera, Depth Camera
Hybrid system	Very different, depending on which systems are working together	GPS & Accelerometer, Gyroscope & Depth Camera

Table 6 Type of Tracking Systems

Some example applications were demonstrated for sensor-based technique, including the retrieval of country information by holding the device in front of a large paper wall map, and querying bibliographic data from books on a bookshelf. For instance, Fitzmaurice [17] in 1993 created Chameleon, using a 4” TV with an electromagnetic tracking sensor. As we described before, Bergé [5] used a Polhemus system for tracking the tablet’s position. Moreover, Hürst et al. [26], used gyroscope and accelerometer sensors on the 3D model of space virtual reality application. As a vision-based technique, Sugimoto in Hotaru [49], used a stereo camera on top of a table to track the position and orientation of a PDA to make an interactive collaboration system, for example transferring files between two devices when they are close together. A set of Vicon cameras were used by Weigel et al. [51] as a motion capture system to track the attached markers on the video projectors for the focus + context system that we described in 2.4. The Tango [54] VR system, developed by Google, gave users the chance to create a virtual world of the real environment by using the built-in depth sensors and camera, which is a hybrid method in device tracking. A Project Tango device (phone and tablet) can plot its environment in the 3D model in real-time. The important factors in device tracking are position tracking, orientation tracking, real-time tracking, and the level of accuracy.

CHAPTER 3 MOBILE FOCUS + CONTEXT SYSTEM

In this chapter, we will first describe a Mobile Focus + Context (mF+C) system and how a mobile phone and projector operate in an mF+C system. We will present how a combination of a phone and a projector works. We describe how a projected image is related to the phone's position. The second part of this chapter is about the system design. We describe how we observed problems, and how we tried to find a solution and our successes and failures. We describe what we learned during the system design.

3.1 Mobile Focus + Context System (mF+C)

In the mF+C system, a mobile phone can be used as a high-resolution display that we call the "Focus" device, and a large display can be used to show an overview of data that we will mention as the "Context" provider. While the mobile phone is being used as a lens, more information will be revealed from the context, which is located exactly behind the phone. In this system, the picture on the phone is totally related to the picture on the large display. For example, if a city map is on the display, by using the phone in front of the screen the user can see that part of the map in a high resolution, which is physically obstructed with the phone (see Figure 23- left).

Figure 23 Mobile Focus + Context System

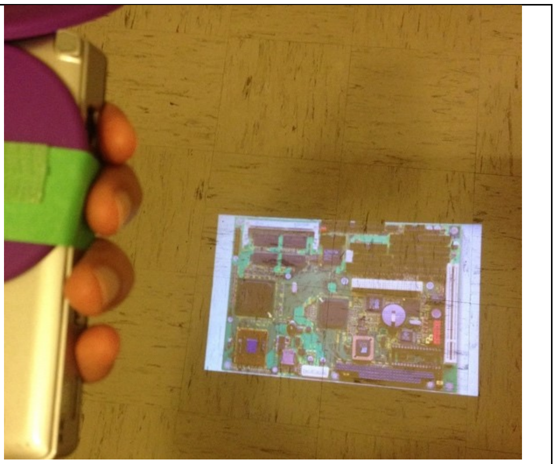
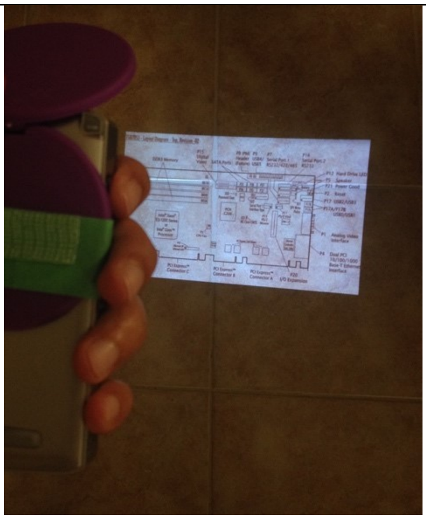
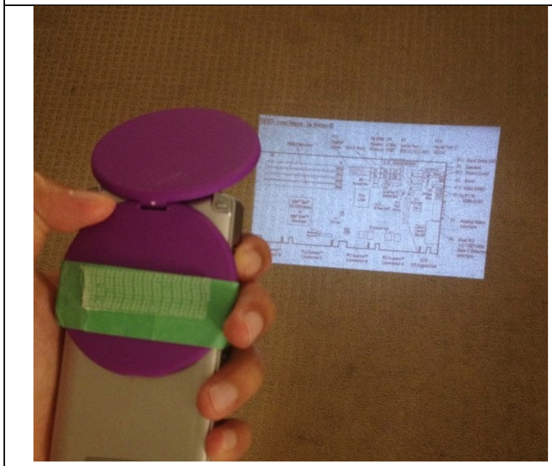
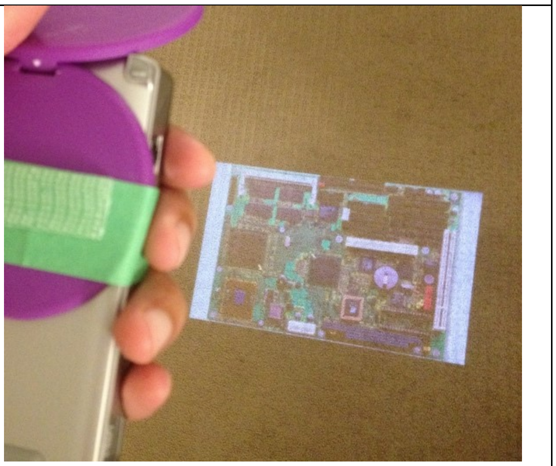
The data on the phone could be the same as the screen data or in a different view. For example, a user can see a *Satellite* version of the map on the phone (Figure 23- left) which is completely synchronized with the *City* map on the large display. Moreover, the user might see more details on the phone, which are not shown on the large display, such as the names of the buildings, streets, or points of interest. In our developed system, we used a projector as a context provider, which could provide a screen in different sizes (from 20” to 120”) regardless of the available physical space. Even small and low power projectors can provide a large screen, which might be not clear, but can provide an overview of the content. In the case of an unclear overview, we are using a mobile phone to see more details in high resolution.

Use of a projector in the mF+C system:

These days, projectors are available in different sizes, such as Pico size (similar to iPhone 4/4s – Optoma PK201: 16x60x117mm), pocket size (a bit smaller than a Mac mini - Optoma ML550: 38x105x105 mm), stationary (Epson EX3220: 294x76x228mm) and classroom (BenQSH963: 170x432x355 mm). They can project on a curtain or floor, and on surfaces that are covered by many types of material, such as a concrete wall, wooden table or an aluminum door. While the pocket-sized projectors are portable and can operate using rechargeable batteries, they can provide a large screen in many places.

Figure 24 Optoma PK201 Pico-projector

To observe how a projected picture delivered by a Pico projector could be useful, we used an Optoma PK201 (Figure 24) projector with a rechargeable battery, in 16x60x117mm dimension, 0.2 kg weight and 20 lumens brightness. This Pico projector with 2.20:1 throw ratio can project a 60-inch screen from 3 meters, and 21 inches from 100 cm distance. The following pictures were taken from a small test that we conducted to show how a 20 lumens Pico projector could provide a picture on different types of surfaces.

 1	 2
 3	 4
 5	 6

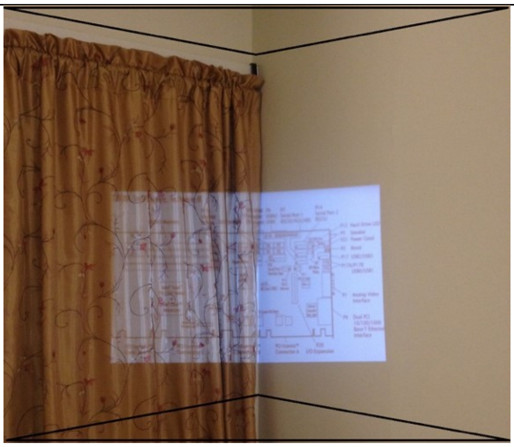
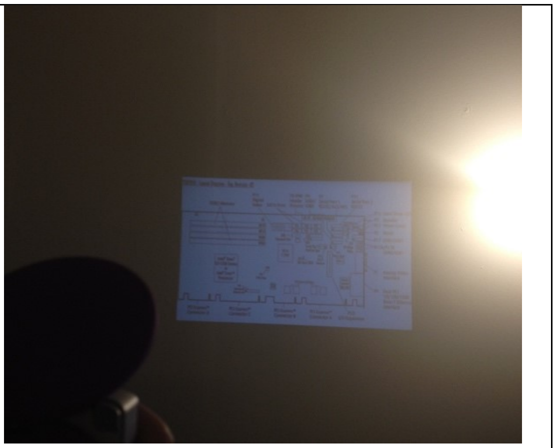
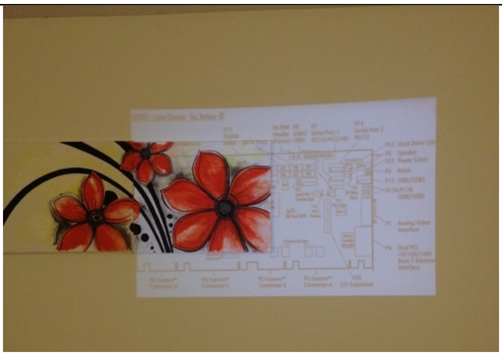
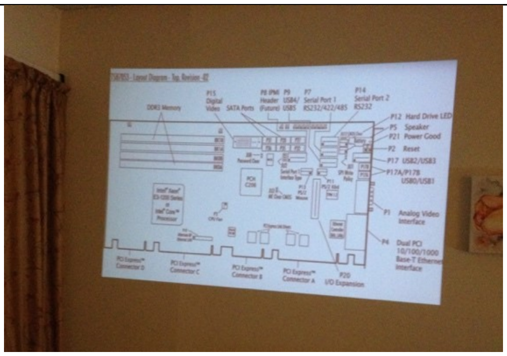
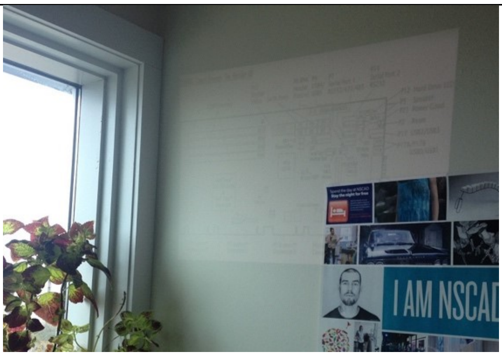
 7	 8
 9	 10
 11	 12

Table 7 Projected pictures in different sizes and on different types of surfaces

In Table 7, picture 1 shows that how a projected image is visible on an uneven surface. We projected a technical diagram on a curtain when two 60-watt LED lamps were ON in the room. While an overview of the picture is visible, in some parts, the texts are readable. The second picture was taken in the same light condition. The picture is projected on the laminated floor. As we can see, shapes, colors and components are visible. However, we knew that there was a name of a company on the top-left white component, but we could not read it. Additionally, the small words on the board and other components were not identifiable. The mF+C system can help us to find and read these texts in detail. In the third and fourth pictures, images with dark and bright backgrounds were projected on the ceramic floor. In the technical diagram with a white background, the texts and shapes were clearly identifiable, but in the electronic board, which has a dark background, the texts were not readable. We found that pictures with brighter backgrounds were more comprehensible than pictures with a dark background. The pictures 5 and 6 are the same as pictures 3 and 4, but they were projected on a rug. In the white diagram, only large texts were readable; however, in the board picture, some shapes were faded, texts were not readable, but colors were distinguishable. Picture 7 shows that the user can project on a non-planar surface. In this picture, a ~50" image was projected to the corner of the room. While the texts on the wall were clear and readable, only an overview of the picture on the curtain was visible. In picture 8, we projected a picture exactly beside the light source. While reading some small words that were close to the light was difficult, most of the texts were clear and readable, and we never missed the overview of the information because of the light. An 86" picture was projected from a 4.2 meters (room width) distance from the wall in pictures 9 and 10. In picture 9, nothing is visible in the area that was projected on the paint; however, the texts of the other parts were readable. While on the painted surface, the projected picture size is increased, but the projector does not have enough power to deliver a brighter picture. In this test, we found that a low lumens projector is not a good choice for having a large screen on the opaque surface. In picture 10, the lamps were turned off, and only one 60-watt LED lamp was ON in another room with 10 meters distance from the testing area. Similar to the picture 9, we have ~86" screen but on a white wall. In this picture, large texts were easily readable, but small words were faded. The pictures 11 and 12 were taken in a room with a large window. The pictures were projected beside the window and affected by the daylight. While some large texts on the technical diagram with the white background were readable, most of the shapes, colors and texts were not visible in the board image with the dark background, and even the overview of the picture was not identifiable. It seems that we needed a projector with more than 20 lumens brightness in this case. The minimum projected size was 21 inches diagonal (in pictures 2,3,4,5 and 6), and the maximum was 86 inches (in pictures 9 and 10). By this test, we identified the environmental factors that affect the projected data, and how an mF+C system can cover those effects and provide access to details of information everywhere.

A projector can project contents in different light conditions. One of the projector properties is the level of brightness, which is a number in Lumens. As a simple definition, the lumen is the amount of the light that is emitted from the light source, so more lumens means more amount of light from the source, and for a projector, this means a brighter projected picture. The environmental light sources have a direct impact on the projected picture. As we can see in Table 7 (picture 8), a 41” projected picture by Optoma PK201, right beside the lamp with 60 watt LED bulb is completely readable from 2 meters. Even in daylight, we can see an overview of the projected content on the surface, but in the direct sunlight, the projected picture from this projector was not visible. In an mF+C system having details of pictures, readable small texts, details of shapes and true colors on the projection area is not necessary where all of them could be identified by using the mobile phone as a Focus device. The minimum requirement for a useful context projection depends on the phone’s width and the distance between the phone and the surface, as well as the phone and the user’s eyes. By keeping a Nexus5 (137.84x69.17x8.59 mm) in hand, 100 cm away from the surface, and 30cm distance from eyes, we found that an area with ~110mm (width) x ~600mm (height) in the surface is physically obstructed by the phone and is not visible. Based on our observation and practical tests, we observed that for a Nexus5 as a Focus device, a 20” diagonal screen (442x248mm, 16:9 aspect ratio) is large enough to see an overview of a picture. We found that ~165mm of projected picture was visible from each side of the phone. The 110mm of the surface, which is blocked by the phone, could be visible through the phone’s screen while using the mF+C system.

A stationary projector can provide a high-resolution picture with high lumens. A short throw projector (projector with throw ratio less than 1) can provide a picture when it is very close to the screen. The stationary projector is movable, but it is not as portable as pocket sized or pico projectors. Some of the smartphones include built-in projectors. Galaxy Beam[4] by Samsung was an Android smartphone that was introduced in 2012 with

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[4] www.samsung.com/global/microsite/galaxybeam/

a built-in DLP overhead projector (Figure 25). The projector had 640*360 resolution, 16:9 aspect ratio, 15 lumens, and 1.8 throw ratio. A 50-inches projection size could be available from 2 meters away from the surface. To compare with the projector that was used in our test, this one has a better throw ratio, which means in closer position to the surface it can deliver a larger picture. In 2014, Samsung released Galaxy Beam 2[5], a new version of Galaxy Beam, which was distributed only in China. The new device has a better hardware specification than the previous Beam, but we could not find the projector's specification for this model. Ayane QS4 is another Android phone with an overhead projector, which uses DLP technology and can provide a screen up to 42 inches with 25 lumens, which is five units brighter than the Pico projector we tested. Unfortunately, there is also no more specification available for Ayane QS4.

Figure 25 Mobile phones with built-in projectors. (Left) Ayane (Middle) Galaxy Beam2 (Right) Galaxy Beam

SANWA released PRJ016[6], a 35 lumens micro projector with an iPhone holder that makes it possible to have a projection of the phone screen. The projector with 1.5 throw ratio and 4:3 aspect ratio can provide a 6-60-inches screen from 20-200 cm. A comparison between the SANWA and our PK201 Pico projector shows that this projector has a better throw ratio (2.2 vs. 1.5) and better lumens (20 vs. 35). All the phones that include an overhead projector can be used as an mF+C system; however, because the phone screen is perpendicular to the projection area, the phone cannot operate as a lens. Since the focus and the context are not in the same plane, the user's attention will be on either the focus or

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[5] www.samsung.com/cn/consumer/mobile-phones/smart-phone/other/SM-G3858MSACHM

[6] direct.sanwa.co.jp/ItemPage/400-PRJ016

the context or switching between both of them. In May 2015, Lenovo introduced Smart Cast, a smartphone with a front built-in laser projector, which will be released soon. While at this time, there is no mobile phone with a projector embedded on the back in the market, we will show that how we can implement a useful prototype of an mF+C system with off-the-shelf portable projectors, such as stationary, pocket size, and pico-projectors.

Figure 26 Mobile phone with built-in projectors. (Left-Middle) SANWA (Right) SmartCast

The ideal location of a projector for an mF+C system is on the back of the phone which would always put the phone in the center of the projection area. Since the projector is embedded on the phone, when the user is looking directly at the phone screen, the projection area and the phone screen are in a line with the user's FoV. The obvious limitation of this approach is that the projected picture will move as the user moves the phone; to overcome this issue later in this chapter we will discuss several techniques for an mF+C system.

Smartphone:

A Smartphone, which in this thesis we will simply mention as "Phone", is a small multifunctional, usually touch-driven device with a moderate-sized (3.5"-5.5" diagonal) high-resolution screen (e.g. iPhone 4s: 640x960 px ~326ppi, Galaxy S6: 1440 x 2560 px ~577ppi). The number of smartphone users worldwide continues to rise from 1.06 billion devices in 2012 to an estimated 2.56 billion by 2018 [55] (Figure 27).

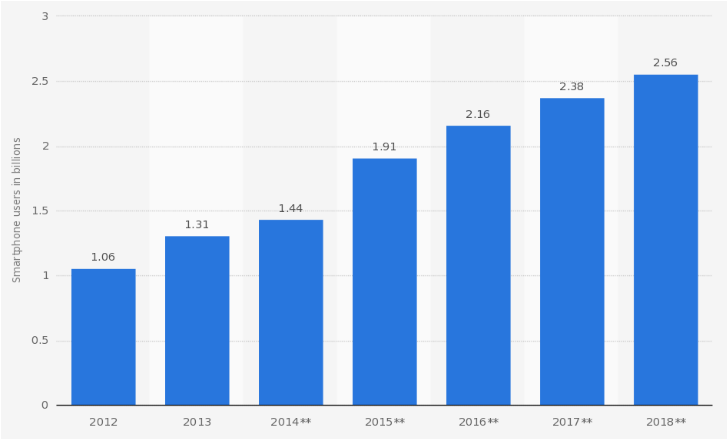

Figure 27 Number of smartphone users worldwide from 2012 to 2018[7]

From the performance point of view, the processing power of smartphones is similar to phablets and tablets (see Table 8), but they are more portable with less weight and can be easily held and used in one hand.

Samsung Galaxy	**Type**	**Release Date**	**Processor**	**Ram GB**	**Display Size**	**Weight**
S4	Phone	Mar13	Quad-core 1.6 GHz Cortex-A15	2	5”	130g
Note3	Phablet	Sep13	Quad-core 1.9 GHz Cortex-A15	3	5.7”	168g
Tab Pro	Tablet	Jan14	Quad-core 1.9 GHz Cortex-A15	1	8.4”	336g

Table 8 Comparison between Galaxy S4, Note3, and Tab Pro

Why have a mobile phone + projector?

In our mockup that we set up for testing the limited version of the mF+C system, we used a stationary video projector to provide an overview of data on a large screen. As we proposed before, in the mF+C system, a mobile phone should operate as a lens. To achieve that level of precision, we carefully observed our environment and a large projected picture on a wall through a simple mobile bumper more than 100 times in a period of 6 months.

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[7] www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/

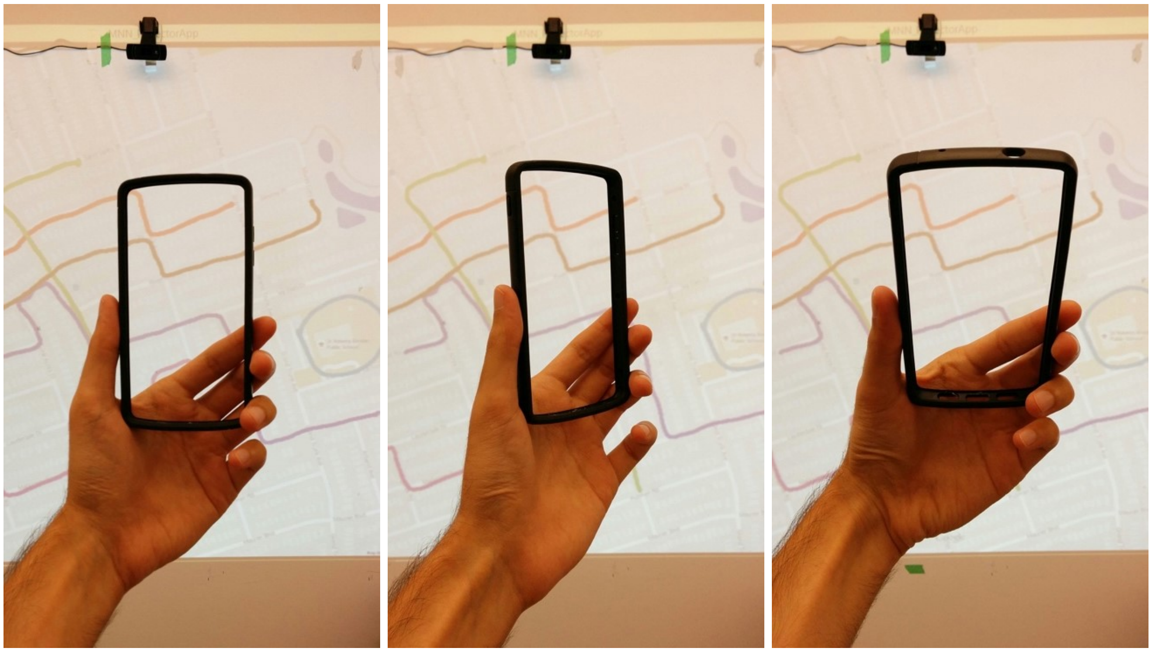

Figure 28 Visible picture through the mobile bumper shows how the picture is related to the position and orientation

We found that the view through the bumper depends on the bumper's location (x, y, z), orientation (yaw, pitch, roll), size and the distance from the object or the surface. In addition, the picture that is visible through the bumper is related to our head's position, orientation and distance from the bumper. We learned that moving bumper forward and backward does not change the size of the objects (it is not working as a magnifier), but affects the field of view. As the first step to create a phone operating as a lens, we made a mockup in 2D space. In this mockup, a user was able to trace a large projected map. The picture on the phone was similar to the part of the map that was blocked by the phone, but it was not related to the user's head or device orientation. To find the exact area of projected picture, which was blocked by the phone, we faced implementation challenges due to the complex geometrical calculation.

The main reason for facing these challenges was because of many variables, such as device position and orientation, and user's head position and orientation, which should be considered in an mF+C system that is supposed to operate in a 3D space.

As two samples of previous research, Hürst [26] used tablet and phone internal sensors to control the virtual camera's orientation and a joystick button on the interface to control the camera's position in the developed application. Moreover, in Bergé's [5] project, the position of the marker was controlled by the hand in between the phone and the desktop display or by phone location. To compare the picture on the phone with these two systems, in our mF+C system mockup, the data on the phone could be related to the mobile phone's position and orientation. The users can trace the large display by moving around the projection area or just by staying at one point in front of the screen and turning the phone left/right or up/down. A method to change the picture according to the user's FoV through the phone's screen is added to this system and is being controlled by moving the phone forward or backward to simulate the content that is visible through the bumper.

Patel in [40], stated how a mobile phone and a Pico projector can be coupled together to create a single information space by identifying three positions for the phone according to the projection position. In the first technique, the phone was in front of the projection in the same direction. In the second approach, the phone was positioned at the side of the projection, and the projected image was updated by doing any interaction on the phone. The third method is a combination of the first and the second methods in which the phone is perpendicular to the projection area while any changes on the phone data will be reflected on the projection. He developed a prototype of the first configuration (Immersive) by using an AR application on an iPhone 4s as a details provider and a stationary short throw projector as a context provider. The developed prototype would just operate if the marker was available and the picture on the screen was only related to the mobile phone position and the distance from the surface.

Projection based on the mobile phone location:

Different types of interactions between a user and large screens can take place by tracking the position of a phone in front of those screens. One of these interactions can be having a high-resolution version of the low-resolution projected pictures on the phone. To develop this idea, we propose three methods, which use a phone with an embedded projector. In the first method, the entire projectable area will be used to present the contents. While the phone is moving the projectable area will also move, and at the same time, the projected contents will change based on the phone's movement direction. In this method, the phone is always located at the center of the projection.

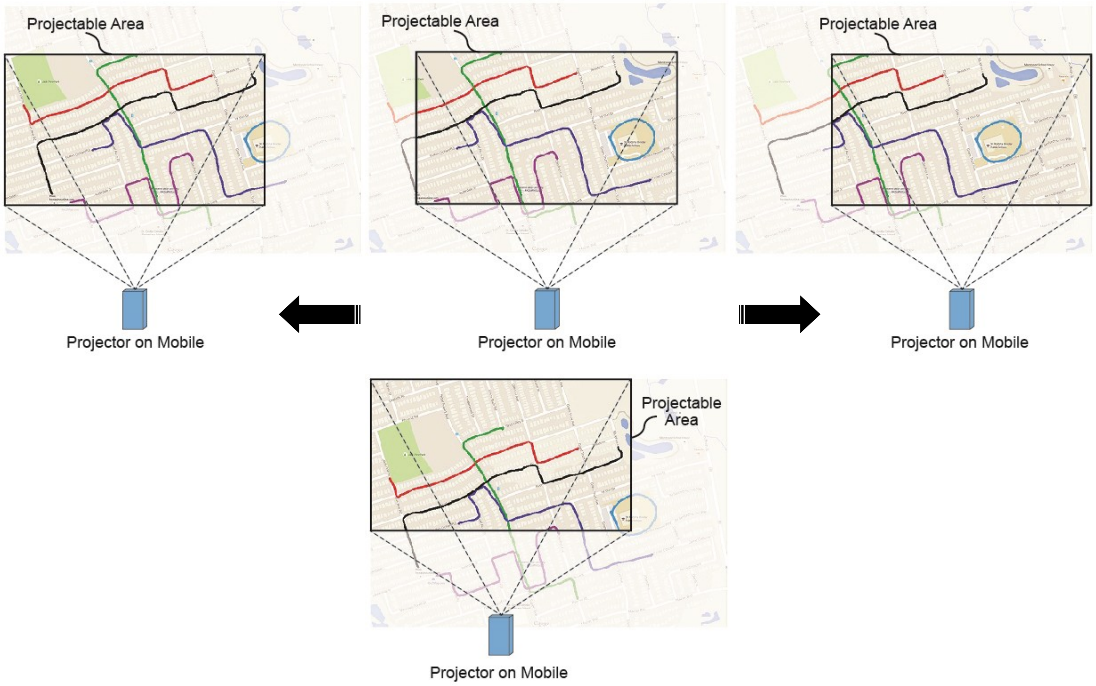

Figure 29 Projectable area when projector is embedded with phone

Figure 29 shows the relation between projectable area and the phone's location and its movement in the x-axis (horizontally). The transparent part in the figure is invisible to the user, and we just intended to show that what is the overview of the map. Figure 29 (top-left) shows that when the phone is moving to the left, the map moves to the right, so more parts of the map from the left side is shown in the new content area. On the other picture (Figure 29, top-right), by moving the phone to the right, the map is shifted to the left, so more parts of the map from the right side is shown in the new content area. In this method, losing the overview of the content is an issue. The illustrated figures show that we are losing the overview of the big map because of the movement, which is just described. For example, when we are moving to the right (Figure 29, top-right), we are losing the park area which is located on the left side of the map. Figure 29-bottom shows that what parts of the map are visible when we are moving to the top-left direction of the initial position.

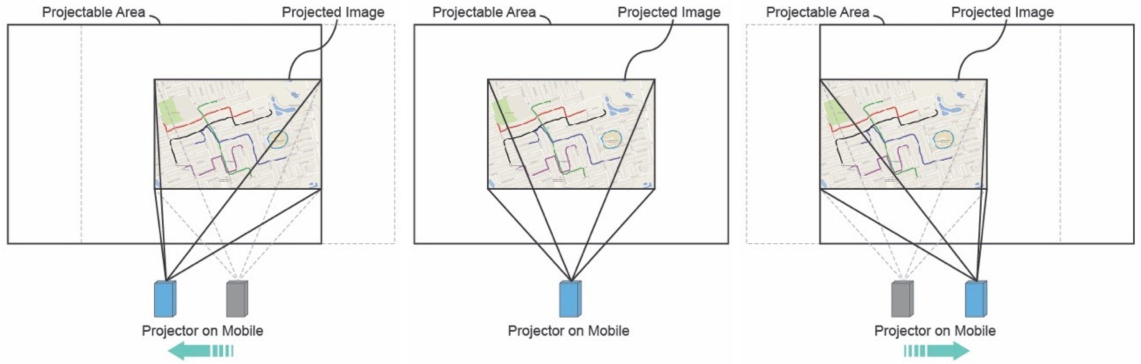

Figure 30 Relation between projection and projectable area

The second method is using a portion of the entire projectable area to show the whole context. In this method, because the projectable area is bigger than the context view, we can change the location of the projected content within the projectable area as the phone moves, such that the projection is effectively kept in a fixed physical position. In the example shown in Figure 30, the center image shows that a portion of the projectable area is used to present the overview of the map, and the phone is aligned with the map vertically at the center. The left image shows that when the phone is moved to the left the projectable area is also moved in the same direction. As a result of shifting the projected image to the right, the phone has moved from the center to the left of the context image while the context remains physically stationary. In this technique, the users would not realize the change of the projected image location.

As we know, the projection area width is equal to the projector distance from the screen divided by the projector throw ratio; therefore, in this method by assuming to use 50% of the projectable area to present the content, there are two ways to have the same projection area as the first method. The first solution is to use a projector with at least 1/2 throw ratio of the one used in the first method at the same location. The second method is using the same video projector and doubling the distance from the screen. In this way, the quality of the picture depends on the projector specification. Some of the projectors (e.g. Casio XJ-H2600) can adjust the brightness and focus features automatically to present a sharp picture; this feature is not currently available in the Pico-projectors.

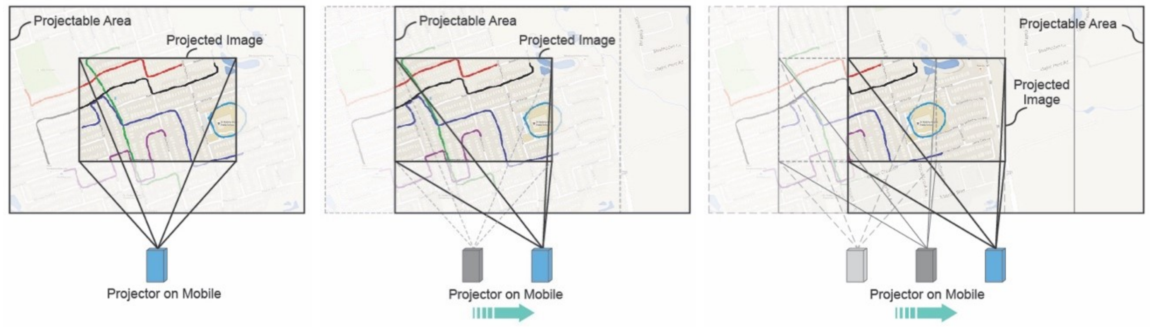

Figure 31 The projection area in respect of the projectable area and phone movement

The third method is a combination of the two previous methods. Figure 31 (from left to right), shows how this method works for horizontal movement (vertical movement is supported in an analogous way). In this technique, a portion of the projectable area is used (image left). By moving to the right until the edge of the projectable area of the initial position, the projected image location remains unchanged. By passing over the edge of the projectable area of the initial position, the projected image will also move, and more data will be revealed. In the other words, by passing the edge of the first projectable area, the content will move in the same direction as phone movement.

In all three methods, moving in the vertical direction on the y-axis is similar to the x-axis. While the mobile movement is happening in a 3D space, considering relocation on the z-axis is important. If we imagine the phone as a lens, moving the phone on the z-axis would affect the ratio of the focus to the context. Assuming that moving the phone forward and backward does not affect the projected image size, moving the phone forward would decrease the range of the focus image on the phone relative to the total context, and moving it backward would increase the focus range until it contains the entire context at some point. In all the described methods, the total projectable context area around the phone will become smaller once the phone moves towards the surface. Moving away will increase the projectable area, but brightness will be reduced. As we examined a 20 lumens Pico projector in daylight, with a clear picture and legible texts in 14pt font size, it seems that brightness would not be a major problem in the daylight or under the artificial lights in the offices.

3.2 System design

For this project, different methods were employed to meet the requirements of an mF+C system. We started by developing a technique to find the mobile phone position. As we described, an mF+C system is supposed to operate as a lens. To simulate this factor on a mobile screen, we should track the phone's position and orientation.

One option to address the phone tracking challenges is using a vision-based technique for finding a marker [28,56]. If a marker is a unique object, it can be easily identified, but if it is part of an object, it would have some limitations to be tracked. Camera vibrations, the speed of movement and light fluctuations have a direct impact on tracking the marker. The projected picture on a concrete wall, a rug, and a curtain have less (or maybe not) detectable features compared to a picture projected on a white planar surface. Therefore, the quality of picture is important in natural feature tracking. In an mF+C, the projector is embedded on the phone, so when the phone is moving the marker also moves which might be an issue for tracking the device location. We developed an Android augmented reality application using the Vuforia[8] plugin developed by Qualcomm in the Unity[9] game engine. In this method, a marker was selected with unique features for adding to a virtual object. At the time that a marker was detected by the phone's rear camera the application starts operation. According to the Vuforia documents, augmentable rating is a range between 0-5 for any uploaded picture. The image with a higher rate is more detectable. Measureable features are sharp, spiked or chiseled detail in the image and features should not be a repeatable pattern. In our informal tests where we used a projected city map, we tried to use some parts of the map as markers, but the images do not have enough trackable features. Therefore, we used Quick Response (QR) barcodes as markers.

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[8] www.qualcomm.com/products/vuforia

[9] www.unity3d.com

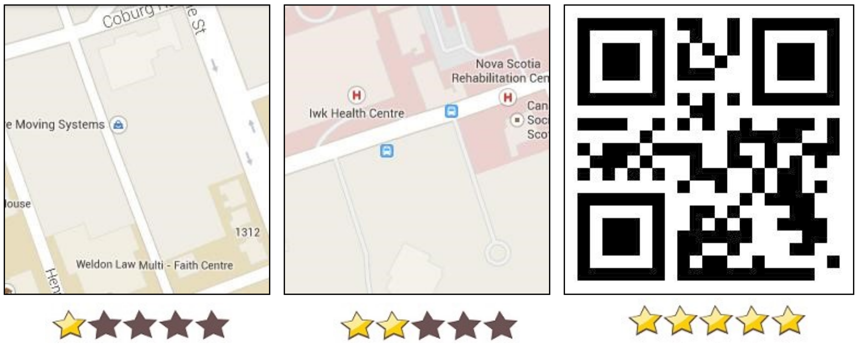

Figure 32 Sample of markers for Vuforia SDK that the level of detectability is rated

A QR barcode has unique features that allow the mobile application to process it very fast from different distances. In an exploration with our Android app on a Nexus4 mobile phone, the readable marker from 100cm away of the camera should be in a square with size at least 7*7cm. When the mobile application is started, the camera stands by to find the marker. By pointing the camera to the marker, a picture would appear on the phone screen. As long as half of the marker is in the camera's FoV, we can move the phone, which would cause the picture on the phone screen to move at the same time. By changing the distance between the camera and the marker, the user's FoV through the phone screen can be also changed.

Our mobile application, which was developed using Vuforia SDK, is not able to identify the QR barcodes when they are part of the projected picture on the wall being projected by a 3100 lumens projector. We believe that it is because of the Vuforia image-processing algorithm. Therefore, because of this issue a person needs to affix the printed barcodes onto the projection area. Another issue is that reading a marker by a phone camera can be affected by various variables, such as camera resolution, autofocus option of the camera, marker density, marker size, shadows and light intensity[25]. For example, when using our application on a phone, which has an 8-megapixel camera, in order to interact with a map from 2 meters, we have to use a square marker, which has the size of at least 14 cm x 14 cm. In order to examine the part of the map that lies outside of the initial region, we have to add extra markers on the map and assign them to the new objects on the mobile application. If we have a large map, we need many markers on it. As another example, for a map with dimension of 3.3m width and 2.5m height, while the phone distance from the wall is 100 cm, we need to pin at least 20 square markers with the size of 7 cm, and also as the markers are visible they may affect the perception of the content overview.

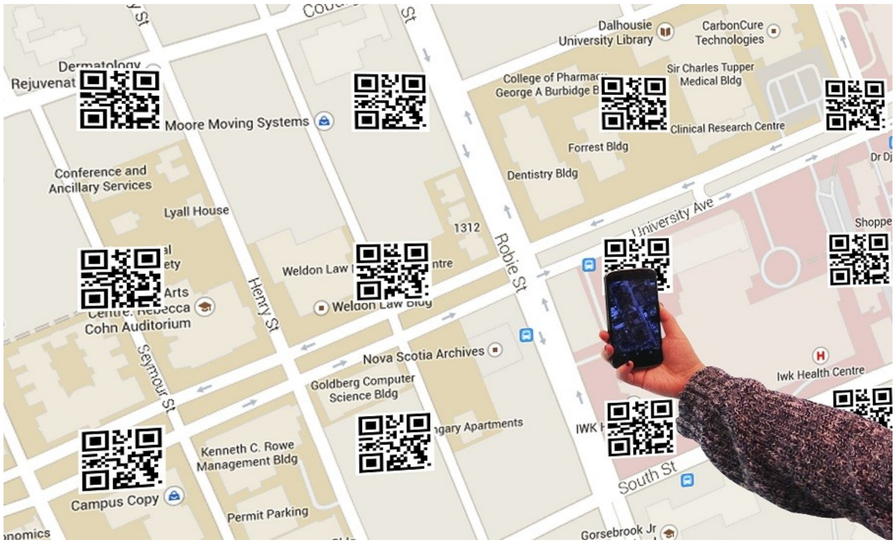

Figure 33 Multiple markers on the wall

Using a depth camera is a vision-based technique tracking option. A depth camera (e.g. Microsoft Kinect, Senz3D), uses 2D camera (RGB) plus an IR projector and a depth sensor to find the depth of the picture in real-time. By adding depth to a 2D picture, the orientation of the camera can be identified based on the captured picture. There are some limitations of using a depth camera such as RGB/IR camera's FoV, such as minimum and maximum visibility distance, and changes in lighting conditions. However, many solutions have been provided to overcome the discussed issues, but they could not solve all the problems because these issues are related to different variables, such as size of the devices, size of the sensors, device application, and image processing algorithms. According to the Tango project, which is a real-time camera feed that processes and compares the acquired results with the pre-designed 3D model of the location, Tango devices do not need any initial position, and real-time position and orientation are available.

Hybrid methods can increase the level of accuracy and extend the operating space. While 2D cameras can be used for position tracking by collecting data from internal sensors, such as gyroscopes, compasses and accelerometers, the speed of movement and the orientation of the device can be added to the application, and they can be calibrated based on the captured picture by the camera.

Figure 34 Head tracking using Senz 3D depth camera

The front camera is available on most of the smartphones, which is an option for user's head tracking, besides the sensor-based technique to acquire the head position and orientation simultaneously. Whereas a depth camera can detect the orientation easier than a 2D camera, we developed a system using a small desktop 3D depth camera on top of the phone to explore the advantages and disadvantages of tracking the position and orientation of the head using the front camera.

We used a customized mobile case for the phone and attached a Senz 3D camera (Figure 34) on top of it. The Intel Perceptual Computing Software Development Kit (PCSDK) was used to track the face feature's position and find the distance between the user's head and the mobile device.

The camera was connected to the Microsoft Surface tablet via USB cable, and a Windows desktop application was developed in C++ to receive the data from the camera. The data was transferred to the mobile phone application using Open Sound Control (OSC) protocol. The Intel Company decided to add the depth camera on the next generation of laptops, phones and tablets; by adding that feature as an advantage for the described method, there would be no need to carry extra devices. The front camera FoV (e.g. Senz 3D, Nexus 4 and Nexus 5 that we used in our prototype) in the range of 5-50cm distance is a big technical issue. The FoV in the first generation of the camera (Senz 3D) is 74◦ diagonal and, for the newest model (RealSense[10] 3D), is 77◦ (RGB) and 90◦ (IR depth). Because the camera is attached to the phone and the user has to keep the phone in front of his head, which is usually between 30-50 cm distances from the face, the user's head is located on the top part

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[10] www.intel.com/content/www/us/en/architecture-and-technology/realsense-overview.html

of the FoV cone. Our observations show that when the user holds the phone in hand with a completely open elbow with minor head movement (10-15cm) from the centerline of the camera's vision, the application works precisely. However, trying to move the head in a slightly wider area (25-30 cm) will cause the head to be placed in the outer range of the supported region by the camera.

Figure 35 Increasing the FoV by adding a wide lens on the front camera

During informal trials of the mF+C mockup using the Senz3D camera, we found that head movement in this wider range was quite common, so we tried to use the front camera to detect the user's eye. With the aid of Lego elements, we added a wide lens on the original lens of the front camera to increase the FoV. Figure 35 (right) shows the lens increased the FoV, and more area of the lab is visible compared to the picture without the wide lens. Similar to the Senz3D camera problem, because the face was very close to the phone, the range of head movement was less than 25 cm. Because we concluded that FoV is a major problem in our prototype, we stopped working on development by using the front camera and switched to using the sensor-based techniques. Using sensors such as gyroscope and accelerometer or eye gaze tracker on the user's head (e.g. smart glasses or hat) are other techniques. Some head worn electronic devices such as Google glass, Spree[11] smart headband, Spree smart cap and Intelligent Headset[12] use built-in sensors to control the features in their applications or user's phones. For example, the smart cap is compatible

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[11] spreewearables.com

[12] intelligentheadset.com

with a music player controller. Moreover, Intelligent Headset is measuring the head orientation to arrange a 3D sound based on the user head direction, location and movement. We considered what a desirable implementation of the mF+C concept might look like. A phone would need to serve as an all-in-one device, working without any add-on sensors or additional projection sources and would be a “Turn It On, Use It” system. To achieve the best solution, the phone should be able to perform the location self-tracking (same as Google Tango project devices) using the front camera for a user’s head tracking and needs to include a projector with a brightness of more than 30 lumens, low throw ratio (<1) and embedded to the back of the phone. With a combination of Nexus 5 mobile phone and a BenQ Joybee GP2 pocket size projector, we made a mockup to observe the behavior of an embedded projector on the phone. The phone was attached to the back of the projector in a position so that the projector lens was at the center of the phone.

Figure 36 A prototype of embedded projector in phone

The projected application was running on a PC and the application’s data was streaming on Chromecast, which was connected to the projector via HDMI port. The projector was operating on a battery, and we used a power bank to turn on the Chromecast. A wireless sensor was attached to the projector to track the position of it. A simple mobile application included a circle; square and rectangle shapes was developed. By moving the projector to the left or right, the projected picture’s location was not changing, but the picture on the phone was changing based on movement direction. However, because of the projector’s throw ratio, the range of movement was short, and it was just a few centimeters, which lead us to the conclusion that the prototype was not a success.

While Lenovo produced a prototype of Smart Cast (a phone with a laser projector in top-front), it seems that there is no technical limitation to have a projector on the other spaces on the phone rather than overhead. We measured the brightness of daylight in our lab, which was 15-30 lumens, so a projector with more than 30 lumens could present the contents on a surface in our office without environmental light problems. By looking at the QS4 Pico projector specifications, we found that it has 35 lumens brightness, which is enough to work in our office. We also can use the floor surface, which is available everywhere as a projection plane. To have a picture with 100cm width with a distance of 100cm (approximately above the waistline), the amount of a projector's throw ratio should be at least one. As we discussed, the PRJ016 Pico projector by SANWA has a 1.5 throw ratio. In addition, Microvision SHOWWX is a laser Pico projector with 1.15 throw ratio. Considering the trends in projector technology, we expect that a better throw ratio (<1) will be available soon. As a summary, we believe that there are no technical limitations preventing all of these characteristics to be included in a single device within the next five years (approximately).

In the next chapter, we will describe the user study that was conducted for this project.

CHAPTER 4 USER STUDY

The study focuses on comparing three designed techniques for linking the phone detail to the projected context. The methods are Immersive (IMS), Side-by-Side (SBS) and Swipe (SWP). In the IMS method, a user would have to use the phone in front of the projection area, such that the picture on the phone is related to the user's position and orientation with respect to the projected picture. In the SBS method, the user can control a pointer on a projected picture by swiping on the phone screen, which displays the same data as what the pointer contains. In the SWP method, the user controls the position of the projected picture by swiping on the phone while the phone is in front of the projected picture. The picture on the phone screen shows the section of the projected map which is physically obstructed by the phone. These techniques will be described in detail in the Interaction Methods section of this chapter. To gain a better understanding of the impact of the context of use on the utility of the techniques, we consider different diagram/content types (and related tasks), and different projection spaces (planar with good projection qualities versus non-planar, multi-colored and multi-textured). We conduct a within-subject laboratory user study to answer the research questions. In this chapter, we present research questions, study design including interaction methods, tasks and conditions, user study procedure and data analysis.

4.1 Research Questions

In this study, we explore the following research questions:

- How does content familiarity affect an mF+C system?
- Does providing detail on the phone screen adequately compensate for poor context visibility due to projecting on non-planar, non-uniform surfaces?
- What are the strengths and weaknesses of the three focus + context linking techniques (Immersive, Side-by-Side, and Swipe)?

4.2 Study Design

As we discussed in Chapter 3, an mF+C system is a mobile device with a powerful projector embedded on the back along with a self-tracking system. To evaluate how the immersive method could be useful on an mF+C system, we developed a mockup of the mF+C system and designed Immersive (IMS), Side-by-Side (SBS) and Swipe (SWP) methods. We included a PhoneOnly technique as a baseline technique (interacting with a single image on the phone using standard multi-touch pan and zoom). In this user study, we compared IMS, SBS, SWP, and PhoneOnly methods and explored the advantages and disadvantages of each method. After method implementation and task design, we conducted informal tests and noted pros and cons of each method, as listed in Table 9.

	Pros	Cons
IMS	-Using body movement, tracing on large content is easier than with SBS/SWP -More accurate than SWP -No need for communication between focus and context	-Needs device (and user) tracking
SBS	-No need for device tracking -Picture on the phone is the same as the marker on the projection	-Tracing (swiping) across a large content area is tedious -Needs communication between focus and context to control the marker position
SWP	-No need for device tracking -Device works as an indicator to show the position of the user in the large context	-Tracing (swiping) across a large content area is tedious -Less accurate than IMS/SBS/PhoneOnly -Needs communication between focus and context to control the projected content position
Phone Only	-No need for device tracking -Single point of focus	-No simultaneous overview + detail -Small overview

Table 9 Advantages and disadvantages of each method

4.2.1 Interaction Methods

Immersive (IMS):

In the IMS method, the data on the mobile application is completely related to the phone's (user's hand) position, orientation and projected image (Figure 37). In this method, while the user's head and mobile screen are in a straight line, the mobile phone works as a lens and the data on the phone is completely related to the section of the projected picture that is physically obstructed by the phone. With a 92-inch picture projected on the wall, the user is free to walk and move around the projection area, using the phone to see more details or different views of the projected picture.

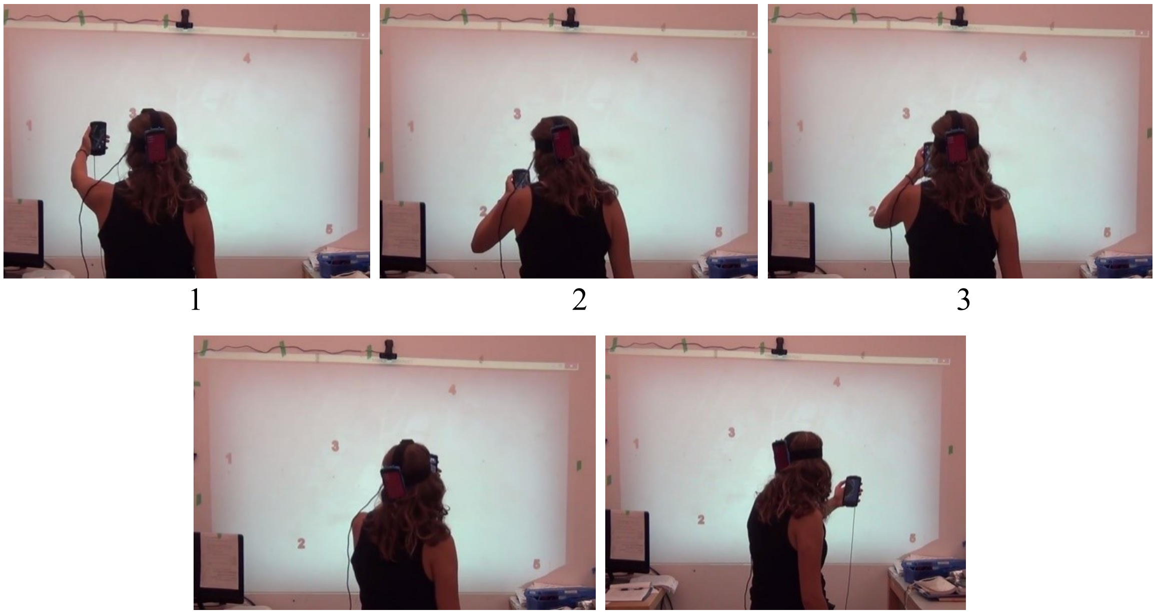

1 2 3
4 5

Figure 37 Interaction methods: Immersive, find streets marked by numbers

In the IMS method, because of the technical constraints (which will be discussed later), the distance between the user and the surface must be between 1-2 meters. The user is free to move in any direction; however, in a situation that the user does not have enough space for movement or does not want to move around the projection, they can tilt their hand left, right, up or down to move the focus around the context. In this method, the user needs only one hand to hold the phone (Figure 38). The FoV on the phone can be controlled by moving the device forward and backward. The text properties, such as font size, weight, and type vary in different pictures. When the projected pictures contain small or unclear text, participants can use the FoV feature to make text more legible.

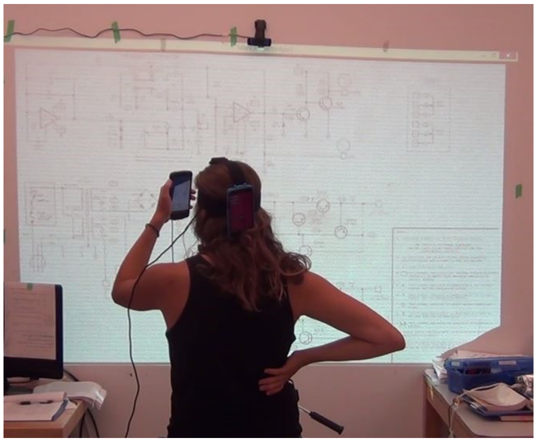


Figure 38 User holds phone by left hand

Side-by-Side (SBS):

The second method is SBS. In this method, a rectangular pointer (or viewfinder) is shown on the projection image (Figure 39), with the same area as is presented on the mobile screen.

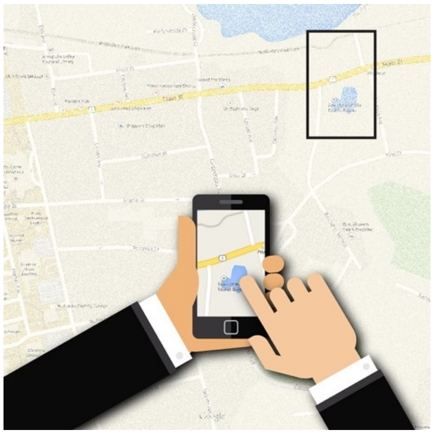


Figure 39 Interaction method: Side-By-Side (SBS)

The user controls the viewfinder position by swiping on the phone. As with all three mF+C techniques, the displayed data on the phone screen is in high resolution, potentially with additional details or a different view of the information visible inside the viewfinder on the projected picture. In this method, there are two buttons for controlling the level of zoom (similar to FoV in IMS method) and a third for resetting to the initial level.

Figure 40 User controlling the viewfinder in SBS method to point on number 1 marker at the left side of the projection

In Figure 40-left, user is looking on the context and swiping on the phone to put the viewfinder on the marker number 1, and then reads the value on the phone (Figure 40-right). The SBS method is not related to the user's position or orientation, so the user can stand wherever they wish so long as they can see the viewfinder and projected picture. For this method, a user can use one hand (depending on hand size and phone dimensions).

Swipe (SWP):

The third method is SWP. This method combines some of the IMS and SBS features. The user holds the phone in front and center of the projection area and the picture on the phone relates to the content on the projected display behind the phone (Figure 41).

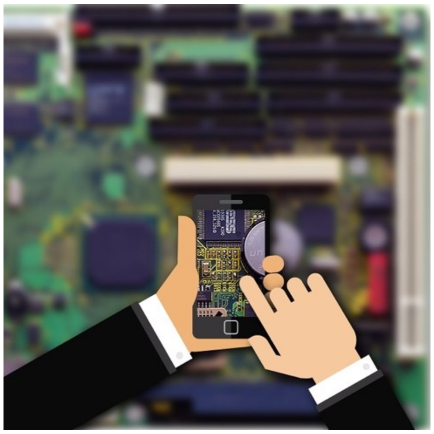


Figure 41 Interaction method: Swipe (SWP)

In the SWP method, there is no viewfinder on the projection. By swiping on the phone's screen, both the picture on the phone and the projected image will move in the same direction. As with the SBS method, there are two buttons for controlling the level of zoom and one for resetting to the initial position.

Figure 42 User controlling the location of the projection in SWP method to point on number 6 marker at the right side of the electronic board

In Figure 42-left, the user is looking on the context to find the number 6, which is not visible on the overview. The user then swipes on the phone to move the picture to the left (Figure 42-right), and they then find the number 6 at the edge of the picture.

PhoneOnly:

In this method, the participants are using the Google photo viewer application to answer questions about two high-resolution images (Figure 40). An overview of the pictures does not reveal any answers; however, in the board picture, the colors (red, brown, black, blue and purple) and shapes (oval, circle, rectangle and square) help participants to find details needed for answers. In the map, restaurant icons are used to guide the participant. Participants use pinch, double tap, and swipe gestures to zoom and pan the images.

Figure 43 Interaction Methods: PhoneOnly task pictures

4.2.2 Conditions

We used each interaction technique under both an optimal projection scenario (a homogenous planar region with good reflective properties for projection) and a suboptimal one (a non-planar region of varying color and texture) - Figure 44.

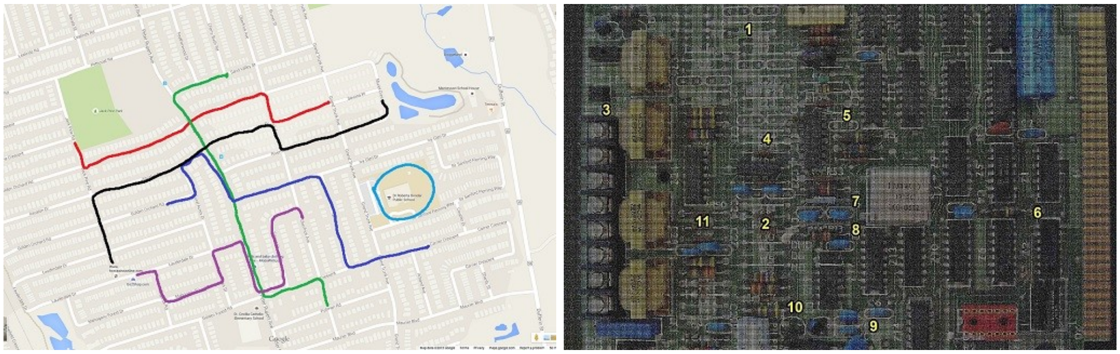


Figure 44 Projected picture conditions: Optimal (left) Suboptimal (right)

In the optimal condition, the large texts are readable, the colors and shapes can be identified, and the projected picture is not very noisy, but some specific details are not available or understandable without using a mobile phone. In the suboptimal condition, pictures are very noisy or too bright/dark, texts are not readable, shapes are not distinguishable, or colors are not identifiable. In this situation, to find the objects in the projection area, the user needs a Focus device to see a high-resolution picture; in this system, we used a mobile phone as a Focus device.

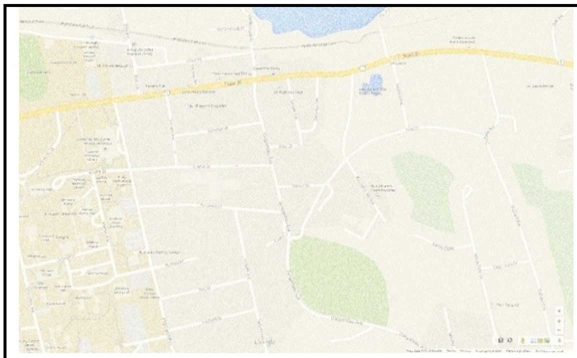
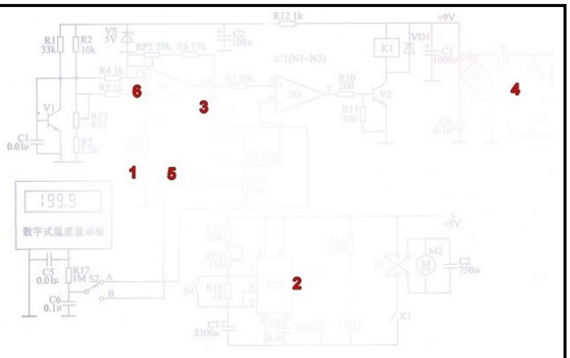
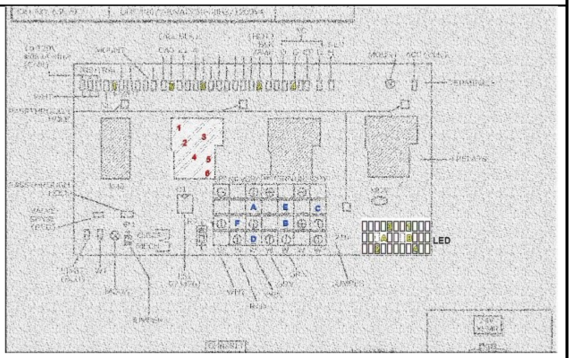
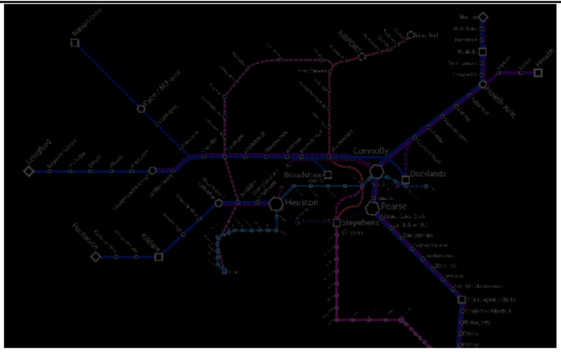
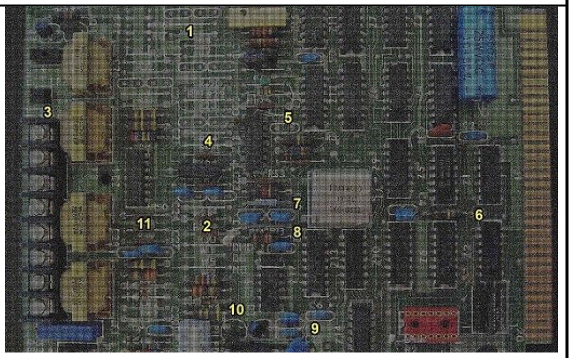
 1	 2
 3	 4
 5	 6

Table 10 Simulated suboptimal pictures

Table 10 shows a range of simulated suboptimal conditions pictures. In Picture 1, the natural markers such as a small lake, large lake, highway, and parks are identifiable on the context; however, the name of locations, such as streets, parks and POIs are not readable. In Picture 2, part of the technical diagram is visible, but there is a spotlight at the center of the design, which caused missing information. Picture 3 is simulated for projection on the non-planar surface (e.g. curtain). When the picture is clear enough, but because of the wrinkles on curtain, the names of streets are not readable over projection. Picture 4 is simulated as a projection on a rug. In this picture, most of the words are not readable, but lines are distinguishable, so we can use the lines as a hint to match with the picture on the Focus device. Moreover, some information is missing in the projected picture, so we are using a Focus device to have a clearer picture and reveal the missing data. Picture 5 is simulated as a projection on a dark surface, and picture 6 is simulated as a projection on a noisy surface.

4.2.3 Type of pictures

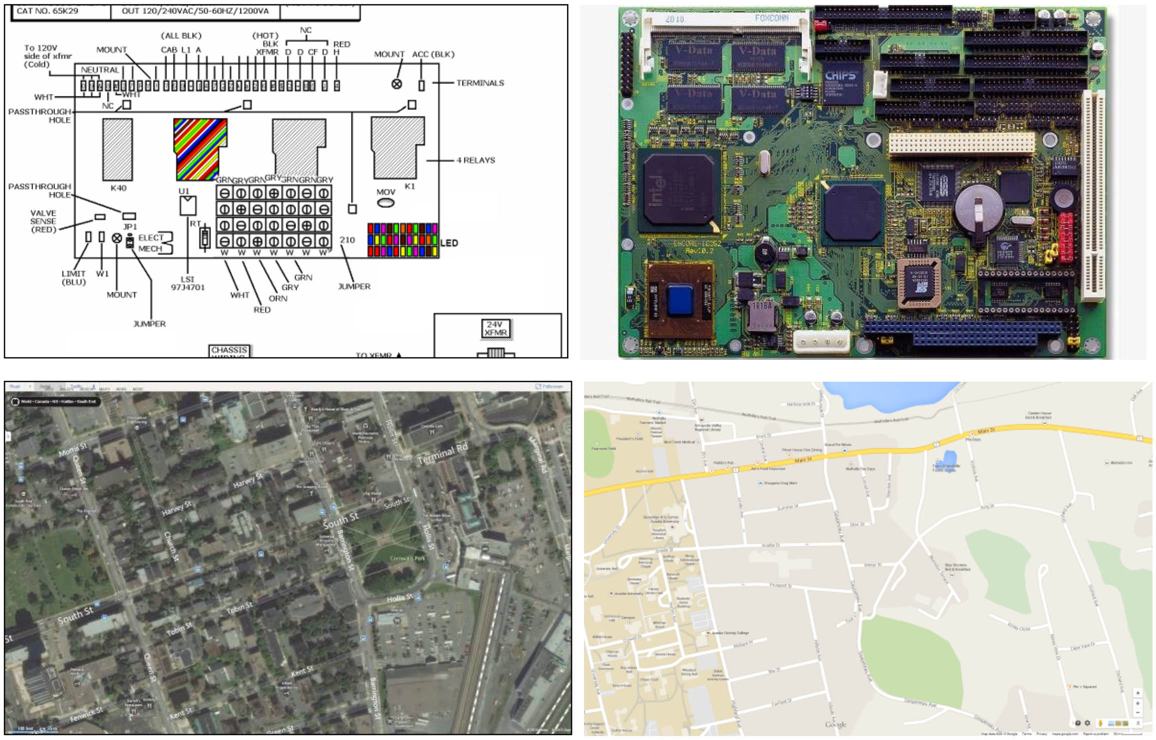


Figure 45 Type of pictures: electronic boards (top), maps (bottom)

To alleviate bias based on specific content formats and tasks, we used several documents falling under two classes: technical diagrams (considered less familiar to the majority of participants) and street maps (considered more familiar) (Figure 45). We also used a range of different tasks within each class: find a single item, find a group of items, trace paths, and find items characterized by natural markers or added markers. Urban maps including transportation network maps, city street maps, and satellite maps were used, which are familiar to many smartphone users. We used electronic boards and circuit diagrams for the technical diagram images.

4.2.4 Tasks

We designed 14 tasks. In each task, participants were asked to find the answer to one or more questions using one of the four methods. Table 11 shows that we have an optimal and suboptimal condition for each method.

IMS				SBS				SWP				PhoneOnly	
OP		SO		OP		SO		OP		SO		Optimal	
MAP	BRD	MAP	BRD	MAP	BRD	MAP	BRD	MAP	BRD	MAP	BRD	MAP	BRD

Table 11 Methods, conditions, types of pictures.

All tasks belong to one of the five categories listed in Table 12. In the first category, the participants find answers based on visible numbers and icons, which were added to the pictures as markers. In the second category, participants have to find the answers by following item properties such as color, size, and shape. In the third category, we asked participants to search in the picture and find answers without any visual hints. Tracing a route and finding an item based on stated position (e.g. top, left, right) and natural landmarks (e.g. lake) are the remaining categories.

Category	**Condition – Picture Type: Question Part**
Finding based on added markers	O-Map: Name of 10 restaurants O-Map: Name of Location marked 1-5 SO-Map: Name of Streets 1-6 SO-Board: 11 markers on board SO-Board: Resistor marked by 1
Finding using color-shape	O-Board: Board with RED and Yellow Connectors SO-Board: BOX of colors, LEDs O-Board (PhoneOnly): Electronic board

Search	O-Board: Positive-Voltage Supply O-Board: DDR 3 Memory SO-Map: Subway Map O-Map (PhoneOnly): Restaurant name
Tracing	O-Map: Start-Endpoint street and websites
Finding based on position and natural features	SO-Map: Raymond Field

Table 12 Task Categories

The predicted time for each task was estimated using an adaptation of the Keystroke-Level Model (KLM). We reviewed at least 10 different adapted KLMs for touch-screen devices, and none of them were valid for our application. For example in this [2] calculation, they measured 70ms for short untargeted swipe, but in our application we need 9 short swipe to move from the left edge to the right edge of the picture and it takes 5.10 seconds, which means each swipe takes about 570ms, includes *70ms (short untargeted swipe) + 500ms(t)*. The *(t)* is the time of application response plus waiting time between swipes and time to assess where the focus has moved relative to the context. When we found that the KLM on touch screen is dependent to properties of the application and type of tasks, we decided to use an adapted KLM, which includes the eight operators as listed in Table 13. Later in this section, we described each operator in high-level details with an example after Figure 46.

Operator	**Guidelines – Time(sec)**
A: Start	Start operation, 0 sec
Q: Time of asking question	Average of five times test for each question
G: Gap between question and mentally preparing or user response	1 sec - Average of five times test
M: Mentally preparing for executing physical actions	1.35 sec - KLM
S: Search for location or answer	1 sec – numerical /visual markers 2 - 15 sec – without marker
P: Pointing to the location of answer	0.20 sec in IMS in any direction 5.10 sec horizontally left⇔right | SBS 6.00 sec horizontally left⇔right | SWP 4.00 sec vertically top⇔down | SBS/SWP

R: Reading answer	1 sec – Text < 2 words 2 secs – Text > 2 words
Z: Physical movement	Varies by tasks/questions
E: End of task	2 secs

Table 13 List of operators and guidelines for calculating the expected time

In some of the tasks we had visual or numerical markers that participants could use to find answers of questions. Some questions were based on identifiable shapes, but they are not marked. For example, in "DDR 3 memory" task, the number of DDR3 memory slots was clearly identifiable, or in "Red-Yellow connectors" task, the largest chip on the board was distinguishable. We had some tasks that required an entire search of the map. For example, in the "Color-streets" task, finding the name of school required an entire search on the map. We assigned a variety of search times based the questions of each task in different methods. The time of pointing was also dependent on the tasks, questions and methods. It was dependent on the location of the markers, location of answer based on the previous question or initial position, and based on the methods. We assigned the time for each question of the tasks based on many variables, such as methods and order of markers.

In IMS methods, the physical movement was important. For example, when the answer of a question was a text on the edge, if participants stand at the center and they just tilt the phone to find the answer, the picture on the phone was in perspective; and it was not legible. Therefore, they should physically move in direction of the answer to be able to read the answer.

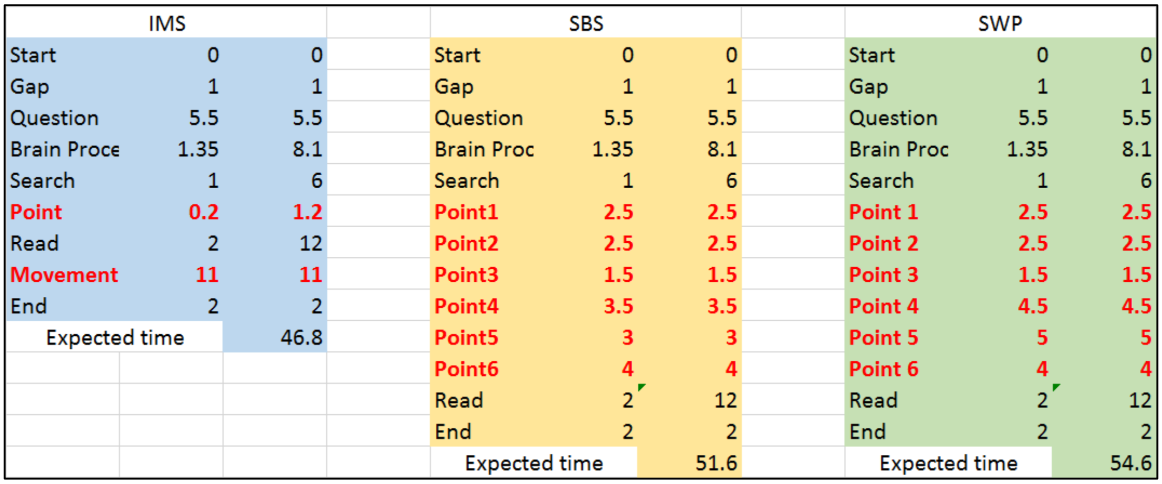
Table 14 represents the expected time calculated for all method of interactions and for each specific task.

Format	**Task**	**Expected Time**			
		IMS	**SBS**	**SWP**	**AVG**
O-Map	Name of 10 restaurants	39.85	40	40	39.95
O-Board	Board with RED and Yellow Connectors	99.2	98.7	96.7	98.20
O-Map	Name of Location marked 1-5	39.05	38.55	39.55	39.05
O-Board	Positive-Voltage Supply	89.85	95.95	96.45	94.08
O-Map	Start-Endpoint street and websites	86.9	111.5	123	107.13
O-Board	DDR 3 Memory	73.1	76.1	77.6	75.60

SO-Map	Name of Streets 1-6	46.8	51.6	54.6	51.00
SO-Board	BOX of colors, LEDs	159.35	154.25	154.25	155.95
SO-Map	Raymond Field	63.95	64.15	66.15	64.75
SO-Board	Resistor marked by 1	63.5	75.8	77.3	72.20
SO-Map	Subway Map	80.35	88.15	91.15	86.55
SO-Board	11 markers on board	72.55	71.35	74.85	72.92
Optimal	PhoneOnly – Map + Board				109.55

Table 14 Expected time for each task in different methods

The expected time is calculated based on the correct way to use the methods. For example, in SWP we asked participants to stand at the center of the projection and hold the phone in the direction of the projection. Table 14 shows that the expected time in SBS and SWP for each task are close to each other. As we described, in SBS the overview is always available, but in SWP while projection is moving, in many tasks, the part of the context is out of the projectable area. In SWP, we measured the time for each question of the task based on the previous question, and we considered that in which question the answer of the next question was visible in the context. The list of all measurements are available on the Appendix G. The following example, which is for the "finding the name of 6 streets" task, shows how we calculated the expected time for each task.



IMS				SBS				SWP		
Start	0	0		Start	0	0		Start	0	0
Gap	1	1		Gap	1	1		Gap	1	1
Question	5.5	5.5		Question	5.5	5.5		Question	5.5	5.5
Brain Proce	1.35	8.1		Brain Proc	1.35	8.1		Brain Proc	1.35	8.1
Search	1	6		Search	1	6		Search	1	6
Point	**0.2**	**1.2**		**Point1**	**2.5**	**2.5**		**Point 1**	**2.5**	**2.5**
Read	2	12		**Point2**	**2.5**	**2.5**		**Point 2**	**2.5**	**2.5**
Movement	**11**	**11**		**Point3**	**1.5**	**1.5**		**Point 3**	**1.5**	**1.5**
End	2	2		**Point4**	**3.5**	**3.5**		**Point 4**	**4.5**	**4.5**
Expected time		46.8		**Point5**	**3**	**3**		**Point 5**	**5**	**5**
				Point6	**4**	**4**		**Point 6**	**4**	**4**
				Read	2	12		Read	2	12
				End	2	2		End	2	2
				Expected time		51.6		Expected time		54.6

Figure 46 Expected time calculation procedure

In all IMS methods for all tasks, we assumed that pointing to the answer takes 0.2 seconds. We measured the physical movement that the user needs to move in front of the 92” projection to find the answer from 1-6 is 11 seconds, but there is no movement in SBS and SWP. In SBS, the amount of time that user needs to move the marker from one side to another side on a 92” screen is ~5 seconds, and at the beginning of the task, the marker is located at the center of the projection area, so we calculated the time that the user needs to point the marker on number 1 and then followed the other numbers. While the SWP method is very similar to SBS in swiping, in some case that user loses the overview of the picture, they need more time to find the markers that we considered in our prediction.

As an example, we are describing in high-level details how we calculated the expected time in each method for this task. In this task, the difference between methods are highlighted by red colors. In this task, six street names are marked with numbers on the map. The location of the markers were highly visible and they were large enough to easily read in the user study area.

In IMS when the picture was projected and participant stood at the center of the projection, we asked participants to press the Start button. There is a time to get the sense that the Start button is pressed and we should go to the next step, which is asking the question, we called this time as a gap and measured as 1 sec. The time of asking each question was measured as an average of five repetitions for each question. From the KLM model, the brain processing time is measured by 1.35 second. In this task, we had six markers, so we calculate six times to have participants think about the question. When participants understand the question, now it is the time for finding the answer. First, they need to search over the map to find the location of the answer. In IMS methods, the user can see the overview of the map. Therefore, in a task that the markers are identifiable, by a quick visual search, they can find the location of the answer, we assumed that it takes 1 sec for searching the location of the right marker. In the tasks, that finding the location of answer is related to the question, the time of finding is varies based on the size, position, color, transparency, contrast and many more variables of the objects. In the case that objects do not have any marker, but they are visible in the context, for example a large square shape, or thick red line on a white screen, user can find them faster than those do not have specific properties, for example finding the name of street on a large map, without any cue. In this task, we had six large numerical markers, so we multiplied 6 by 1 sec for all search. When the user finds the location of the marker, then they should find the answer by pointing to the marker. In IMS, the user is free to move or tilt the phone to point to the marker, but tilting the phone is not a good solution for reading the names at the side of the projection, when the displayed picture is in the perspective. So in IMS it is expected that the user moves to the sides to find the answers, which has a time cost. We assumed 0.2 sec as a time for controlling the phone to point to the marker, regardless of physical movement. In this task, by 6 markers we multiplied 6 to 0.2 sec to calculating the pointing time. We measured the physical movement time for each task based on the questions, and the location of markers. For example, in this task, finding the answer of number 1 and 2 needs physical movement, but marker 3 is very close to the number 2, so user can find the answer of it without additional movement. After that finding the answer for marker 4 needs physical movement to the right side of the projection area, but no more movement is required for number 5 and 6. We calculated 11 second movement for this task. At the time user pointed to the marker, he must read the answer on the phone, which needs context switching from projection to the mobile screen that costs time. Then user have to identify the answer on the phone. In this task, the markers were pointed to one specific word and there was no more word on that area, but in the other tasks that might be 2-3 words are visible in the phone screen, user needs to justify the location of the phone to find the correct word. We considered the context switch time, and justifying time in "pointing" time. The reading time is different when some of the answers are short but they are not English words or they have more than 2 words. We assumed that 1 sec for up to 2 word/number/character answers and 2 secs for more than 2 words answers. In this task, we multiplied 6 to 2 sec for reading the answers. When participant found the answer of marker 6, he is waiting to know what should he do, which takes a waiting time, so we asking him to press the End button. This request and user preparation to operation takes a time that we assumed 2 secs for pressing the end button. The list of method encoding for this task in IMS is:

Q1: 1- Start the task (A) 2- Waiting for question (G) 3- Asking question (Q) 4- Mental preparation (M) 5- Search for marker 1 (S) 6- Physical movement to location of marker 1 (Z) 7- Point the phone to marker 1 (P) 8- Read the value of marker 1 (R)	Total: A+G(1)+Q(5.5)+M(1.35)+S(1)+ Z1(3.55)+P(0.2)+R(2) = 14.6
Q2: 1- Mental preparation (M) 2- Search for marker 2 (S) 3- Physical movement to location of marker 2 (Z) 4- Point the phone to marker 2 (P) 5- Read the value of marker 2 (R)	Total: M(1.35)+S(1)+Z2(2.45)+P(0.2) +R(2) = 7
Q3: 1- Mental preparation (M) 2- Search for marker 3 (S) 3- Point the phone to marker 3 (P) 4- Read the value of marker 3 (R)	Total: M(1.35)+S(1)+P(0.2)+R(2) = 4.55
Q4: 1- Mental preparation (M) 2- Search for marker 4 (S) 3- Physical movement to location of marker 4 (Z) 4- Point the phone to marker 4 (P) 5- Read the value of marker 4 (R)	Total: M(1.35)+S(1)+Z3(5)+P(0.2)+R(2) = 9.55
Q5: 1- Mental preparation (M) 2- Search for marker 5 (S) 3- Point the phone to marker 5 (P) 4- Read the value of marker 5 (R)	Total: M(1.35)+S(1)+P(0.2)+R(2) = 4.55

Q6: 1- Mental preparation (M) 2- Search for marker 6 (S) 3- Point the phone to marker 6 (P) 4- Read the value of marker 6 (R)	Total: M(1.35)+S(1)+P(0.2)+R(2)+E(2) = 6.55
A+G(1)+Q(5.5)+6M(1.35)+6S(1)+Z1(3.55)+Z2(2.45)+Z3(5)+6P(0.2)+6R(2)+E(2)	Total time task completion =46.8

In SBS, when user can see the overview of picture, the time for some of the operators is same as IMS method. The question time, gap, mental preparation, search on the overview, reading the answers and pressing the end button are similar to IMS. One difference is that in SBS, user do not need a physical movement, but the pointing to the location of marker is different. At the beginning of task, the viewfinder is in the center of the projection. In this task, when participant find the number 1, he must look at the context to know the location of the viewfinder. At the same time of looking on the context, he should swipe on the phone screen to control the location of the pointer and put the viewfinder on the marker 1. There is a context switch between projection and phone screen to read the value of marker. Then he needs a mental preparation to find the number 2 and there is another context switching cost when he needs to look at the projection. Now it is the time for pointing to number 2 read it and then continue to the end. In SBS, we measured each pointing time for each question of tasks, based on many variables, such as the type of tasks, visibility of the markers (if exist), visibility of the answers, the location of the answers which needs deep search, and the answer of previous questions when the user can recall the location.

The method encoding for this task in SBS is:
Q1: A+G(1)+Q(5.5)+M(1.35)+S(1)+P1(2.5)+R(2) = 13.35
Q2: M(1.35)+S(1)+P2(2.5)+R(2) = 6.85
Q3: M(1.35)+S(1)+P3(1.5)+R(2) = 5.85
Q4: M(1.35)+S(1)+P4(3.5)+R(2) = 7.85
Q5: M(1.35)+S(1)+P5(3)+R(2) = 7.35
Q6: M(1.35)+S(1)+P6(4)+R(2)+E(2) = 10.35
Total: A+G(1)+Q(5.5)+6M(1.35)+6S(1)+P1(2.5)+P2(2.5)+P3(1.5)+P4(3.5)+P5(3)+P6(4)+E(2) =51.6

In SWP, at the beginning of the task, user can see the overview of the picture, so similar to SBS, the time for some of the operators is same as IMS method. The question time, gap, mental preparation, search on the overview, reading the answers and pressing the end button are similar to IMS and SBS. In the when user is stand at the center of the projection, and holed up the phone in direction of the projection, he wants to find the value of number 1. When he is looking at the context, he swiping on the phone screen to move the projection and put the marker 1 on the position that he could be able to see the answer of the marker. In SBS, there was a viewfinder which works as a pointer and user was completely sure that the data on the viewfinder is exactly same as on the phone screen, but in this method, justifying the location of the marker to be in a right place that user can see the answer on the phone is more challengeable that SBS. To justify the location, user needs more context switching between projection and the phone screen, which costs the time. In this task when user moved the projection to the right side, after finding the number 1, only a quarter of the map is visible on the projection. To find the answer of number 2, user can find the marker very fast by a quick visual scan on the small map. But after user finding the answer of number 3, the number 4 is not visible on the overview. At this time user should move the map until to put in the initial position or finding the location of the next marker. In this case, pointing to the next marker takes time to find the location of marker, but we believe that most of these actions will be happened during a short period of time and many of them are happened at the same time. For example, when user moving the projection to the left he also visually scan the new area that is available, so there is no extra search time. In addition, if he needs 5 second from marker 3 to 4, when he is moving the projection to the left, and he find the marker 4 on the right when the whole projection is visible, now he needs only 2 seconds to reach the new location, which is marker 4. Same as SBS, we measured each pointing time for each question of tasks, based on many variables, such as the type of tasks, visibility of the markers (if exist), visibility of the answers, the location of the answers which needs deep search, and the answer of previous questions when the user can recall the location.

The method encoding for this task in SWP is:
Q1: A+G(1)+Q(5.5)+M(1.35)+S(1)+P1(2.5)+R(2) = 13.35
Q2: M(1.35)+S(1)+P2(2.5)+R(2) = 6.85
Q3: M(1.35)+S(1)+P3(1.5)+R(2) = 5.85
Q4: M(1.35)+S(1)+P4(4.5)+R(2) = 8.85
Q5: M(1.35)+S(1)+P5(5)+R(2) = 9.35
Q6: M(1.35)+S(1)+P6(4)+R(2)+E(2) = 10.35
Total: A+G(1)+Q(5.5)+6M(1.35)+6S(1)+P1(2.5)+P2(2.5)+P3(1.5)+P4(4.5)+P5(5)+ P6(4)+E(2) =54.6

We calculated the expected time for all other tasks, which are available in the Appendix G, using the described formula.

Different pictures and tasks were used for the Optimal and Suboptimal conditions; therefore, we use the same approach for comparing time between these conditions. Participants performed all tasks using all methods, so we used all tasks for method comparison.

Optimal vs. Suboptimal Expected Time (sec)			
Optimal		Suboptimal	
Name of 10 restaurants	39.95	Name of Streets 1-6	51.00
Board with RED and Yellow Connectors	98.20	BOX of colors, LEDs	155.95
Name of Location marked 1-5	39.05	Resistor marked by 1	72.20
Positive-Voltage Supply	94.08	Subway Map	86.55
Start-Endpoint street and websites	107.13	11 markers on board	72.92
DDR 3 Memory	75.60		
Total:	454.02	Total:	438.62

Table 15 Group of tasks for comparing time between Optimal and Suboptimal

Table 15 shows that six optimal tasks have similar total times with the five suboptimal tasks, so we are comparing these two sets with times that participants spent on each to find the differences between the conditions.

Similar to the condition comparison, we used sets of tasks that are similar in expected time for comparing the familiarities with the type of content.

Map vs. Board Expected Time (sec)			
Map		Board	
Name of 10 restaurants	39.95	DDR 3 Memory	75.60
Name of Location marked 1-5	39.05	BOX of colors, LEDs	155.95
Start-Endpoint street and websites	107.13	Resistor marked by 1	72.20
Name of Streets 1-6	51.00	11 markers on board	72.92
Raymond Field	64.75		
Subway Map	86.55		
Total:	388.43	Total:	376.67

Table 16 Group of tasks for comparing time between Map and Board

Table 16 shows that the total expected time for six map tasks (388.43) are close to the four board tasks (376.67); so we compared these two groups of tasks with the times that participants spent on each task to find the time relation between Map and Board.

We are using the phone to see high-resolution pictures, so in the PhoneOnly method there were only Optimal pictures. To compare the PhoneOnly method with the other mF+C techniques, we calculated the expected time of task completion for a PhoneOnly method on board task using modified KLM assessment. We selected one board from a group of the mF+C methods with similar type of tasks - Table 17.

PhoneOnly vs. mF+C methods Expected Time (sec)			
PhoneOnly		Optimal mF+C system	
Optimal Board	52.15	Board with RED and Yellow Connectors	98.20

Table 17 Group of tasks for comparing time between PhoneOnly and mF+C methods

Each interaction method has one map and one electronic board. We made a counterbalance for an order of assigning the methods, conditions, and tasks for each participant (Table 18). In this table, for each user, the first character stands for condition (Optimal, Suboptimal); the second character is the type of picture (Map, Board). Four tasks were completed for each F+C method, and the final two assignments in each ordering (after the dash) are for the PhoneOnly method.

ID	1,13,25	2,14,26	3,15,27	4,16,28
	OM|OB|SM|SB - OM|OB	OB|SM|SB|OM - OB|OM	SM|SB|OM|OB - OM|OB	SB|OM|OB|SM - OB|OM
ID	5,17,29	6,18,30	7,19,31	8,20,32
	OM|SM|SB|OB - OM|OB	SM|OB|SB|OM - OB|OM	OB|SB|OM|SM - OB|OM	SM|OM|OB|SB - OM|OB
ID	9,21,33	10,22,34	11,23,35	12,24,36
	OB|OM|SM|SB - OM|OB	OM|SM|OB|SB - OM|OB	SB|SM|OM|OB - OM|OB	OM|SB|OB|SM - OB|OM

Table 18 The order of methods that assigned to each participant

4.2.5 Experiment

A within-subject design was used with three different interaction methods (IMS, SBS, SWP), simulated projection conditions (Optimal, Suboptimal), and content types (Map, Board).

Group1 – 12 Participants	IMS	SBS	SWP
Group2 – 12 Participants	SWP	IMS	SBS
Group3 – 12 Participants	SBS	SWP	IMS

Table 19 The order of methods for each group of participants

For testing the methods, we divided participants into three groups (see Table 19). The method order for the first group of participants was IMS-SBS-SWP, for the second group it was SWP-IMS-SBS and for the last group it was SBS-SWP-IMS; each includes 12 participants to perform all tasks in different conditions and uses different interaction methods. While participants were completing tasks on IMS, SBS, and SWP, they had to perform two more tasks, in the PhoneOnly method (one Map, and one Board).

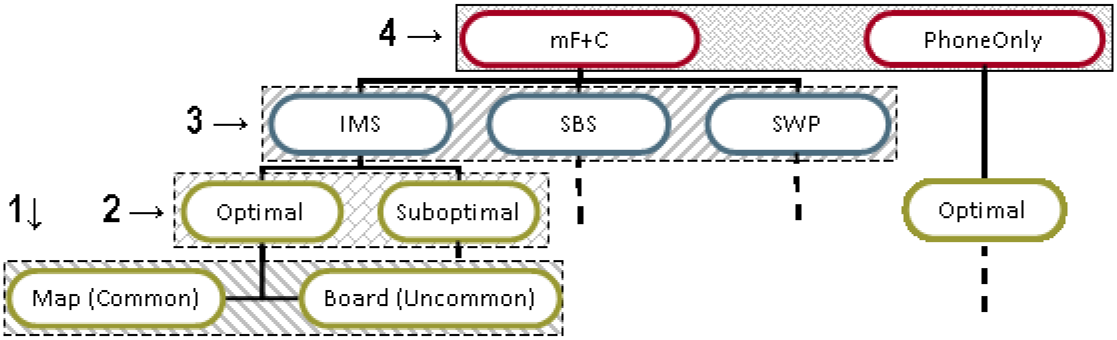


Figure 47 Structure of the experimental design

Figure 47 represents the structure of the experimental design. We use this structure to organize our results in Chapter 5 (Results), and consider how each level is related to others and the research questions in Chapter 6 (Discussion).

4.3 Mockup

In this section, we describe the hardware and software used in the study.

4.3.1 Apparatus

We implemented an experimental apparatus to evaluate the user experience of mF+C system for our study. We used a Polhemus[13] G4, which is an electromagnetic-field based sensor and a 6-degree of freedom (DoF) motion tracking system for tracking the mobile phone and the participant's head position.

Figure 48 Polhemus G4 system (left) Sensor on phone (right)

G4 is a precise device, but because it operates using an electromagnetic field, any metal objects near the sensors or the "Source" can have distortion effects on the collected data. When we tried to attach a sensor directly to the back of the phone, we received strange data because of the phone's battery and other modules that generate an electromagnetic field. We attached the sensor to a piece of rubber ribbon (Figure 48), so participants had to put their fingers in between the ribbon and phone, but they could hold the phone with their left or right hand. Another limitation of the Polhemus is the range of the supported area. The device datasheet shows that the optimal performance range is 3.66m, but in our exploration the best distance of the sensor from the source was 2.6 m on x-axis, 2.4 m on y-axis and 2m on z-axis. More details of the system set up will be described in detail in the following sections. We also used an ultra-short throw projector, manufactured by NEC[14], with a throw ratio of 0.3 to 1. The projector provided a 92-inch projectable area, and the phone could be held within 0.5 meters from the projection without any shadow. The projection

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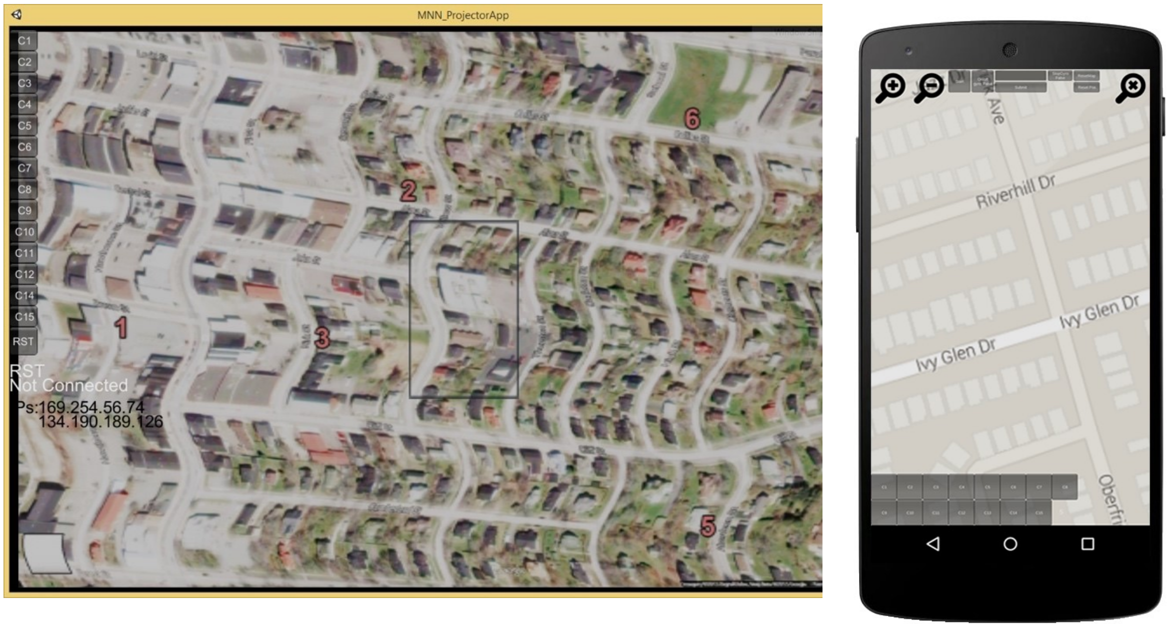
[13] www.polhemus.com

[14] www.necdisplay.com/p/multimedia-projectors/np-u300x?type=support

brightness is 3100 lumens, which is 6+ times brighter than current commodity pocket-sized projectors. In the Immersive and Swipe methods, the initial distance of the phone is 1.5 meters from the screen. In this location, the phone operates as a piece of glass, which means the picture on the phone is the same as the part of the projection that is located exactly behind the phone. Moreover, the large projector and phone are not attached, so if we take the phone closer to the projection, it will not decrease the size of the projection. Generally, once the projector is coupled with the phone, we can use the entire projectable region for context without making adjustments due to phone movement. Using a large projector means losing the portability of a pico-projector.

4.3.2 Software



RST
Not Connected
Ps:169.254.56.74
134.190.189.126

Figure 49 Desktop application (left) Mobile application (right)

A Windows desktop application was developed and installed on a PC to control the projector, and an Android application was developed for a mobile phone. Both applications were developed in the Unity game engine using C# scripts. All game objects in Unity have "transfer" and "rotation" properties with x, y and z variables that let us control the objects' position and orientation easily. Unity's main camera has "transfer", "rotation" and "field of view" properties, which are very useful for controlling the FoV and controlling the picture on the phone with sensor data.

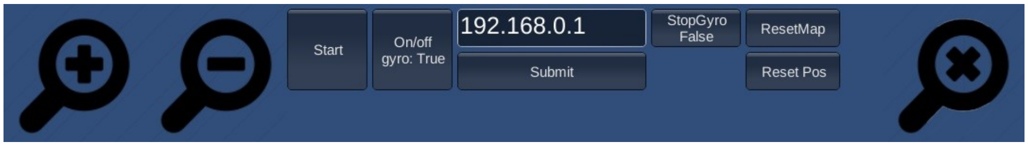


Figure 50 Mobile application settings

On top of the mobile application screen, there are magnifier icons for controlling the level of FoV (in SWP and SBS). There is a box for setting the IP address for communicating with the PC and a button to turn on/off the Gyroscope sensor, which is used in IMS to control the orientation of camera. There are reset buttons to reset the position of the camera in the application and the position of the projected map to the initial position. The Start button is used to start logging the sensor data for each task.

Figure 51 Mobile application task controller

On the bottom part of the application screen, there are 15 buttons. The first 12 buttons (C1-C12) are designed for changing the main tasks, and last three buttons (C13-C15) change the training tasks which are designed to provide a better understanding of what is going on when the methods are in operation. By clicking on the Start button, all buttons except the magnifiers and Start (which changes to End) become hidden. By touching the End button, the task will stop, and the entire key will be visible. Similar to the mobile app, there is a task controller on the desktop app, which can be shown or hidden by pressing the "G" key on the PC keyboard. The application displays the PC's IP address and the mobile phone connection status.

To control the viewfinder in SBS (and same for projected image in SWP), we first proposed a mode where touching an edge of the screen would move the window quickly in the same direction which required less finger movement on the screen. However, we finally agreed to use the normal swipe gestures, which is a common method of interaction for touch screens.

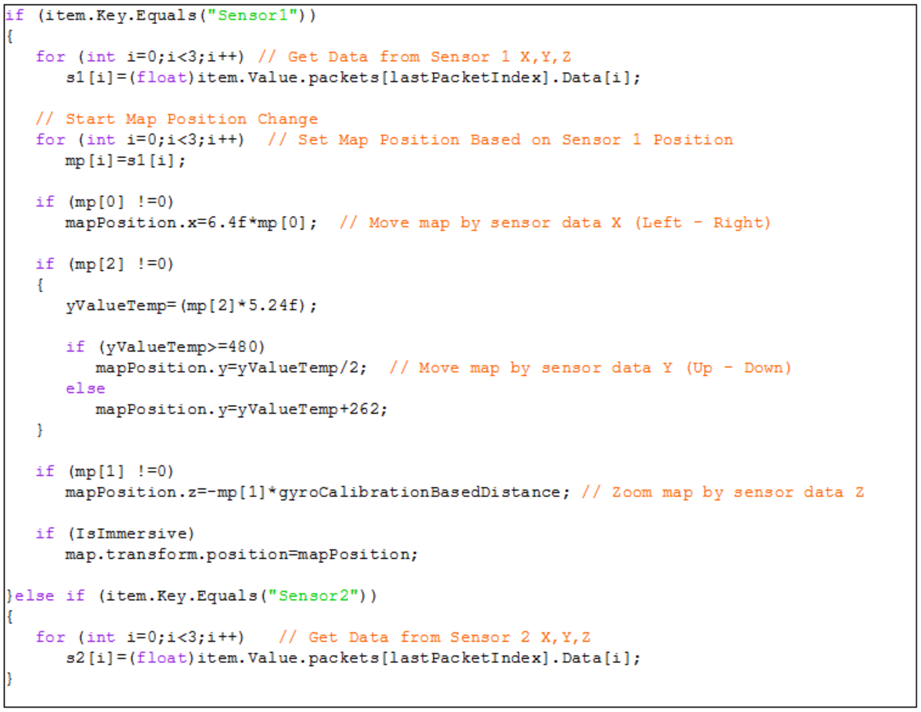
The Polhemus SDK was used to collect the position (x, y, z) from each sensor relative to the source position, and this data was sent from the PC to the mobile phone at approximately 120 fps.

```
Sensor 1:  07158|   100.594  127.787  39.876|  -105.376  20.690  22.035|
Sensor 2:  07158|   135.008  129.517  39.214|   178.461  31.267 -32.084|
Sensor 1:  07161|   100.616  127.766  39.885|  -105.403  20.706  22.024|
Sensor 2:  07182|   135.036  129.463  39.473|   178.391  31.355 -32.170|
Sensor 1:  07185|   100.610  127.771  39.866|  -105.388  20.676  22.017|
Sensor 2:  07185|   135.033  129.500  39.323|   178.422  31.300 -32.107|
Sensor 1:  07188|   100.643  127.742  39.890|  -105.417  20.697  22.006|
Sensor 2:  07188|   135.028  129.573  39.164|   178.480  31.248 -32.046|
Sensor 1:  07191|   100.637  127.749  39.895|  -105.417  20.696  22.014|
```

Figure 52 Schematic of communication between devices and applications

There are two applications running on the PC, one for collecting the Polhemus sensor data and another one for controlling the projected picture. Moreover, the location of the user's finger while swiping on the screen (in SBS and SWP methods) was sent from the mobile application to the projection controller. A real-time port listener function on the desktop application receives the bundle of data from the mobile application and the Polhemus application. It then applies the appropriate functions, such as moving the marker (in SBS) or projected picture (in SWP). On the mobile application, similar to the desktop application, a real-time port listener receives Polhemus data and changes the position of the picture in the IMS method.

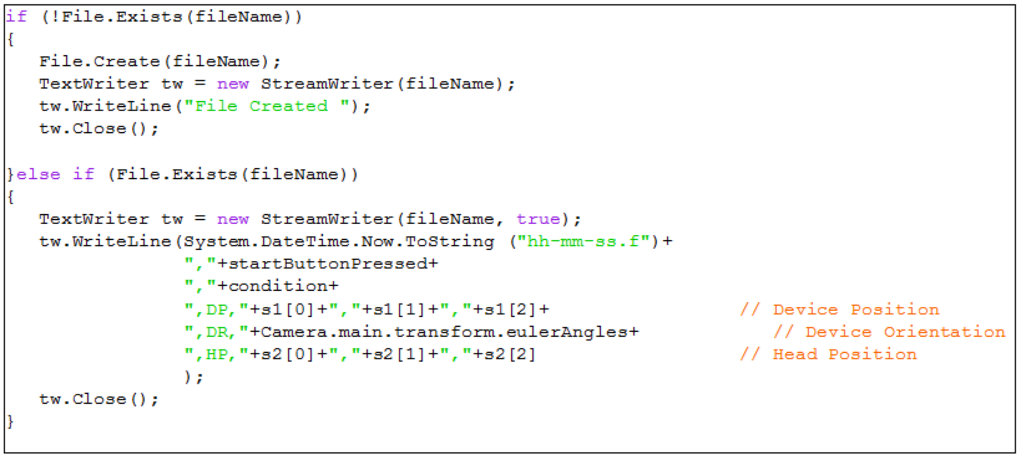
We used the OSC protocol for handling the communication between the applications. On the client side of the OSC protocol, each packet of data includes the name of the sender, the destination IP, the destination port and an array of data. On the server side, the OSC opens a port to listen, checks the name of the sender and passes the data to the right function. Figure 53 shows an example of the OSC listener function on the mobile application while the port is open.



```
if (item.Key.Equals("Sensor1"))
{
   for (int i=0;i<3;i++) // Get Data from Sensor 1 X,Y,Z
      s1[i]=(float)item.Value.packets[lastPacketIndex].Data[i];

   // Start Map Position Change
   for (int i=0;i<3;i++)  // Set Map Position Based on Sensor 1 Position
      mp[i]=s1[i];

   if (mp[0] !=0)
      mapPosition.x=6.4f*mp[0];  // Move map by sensor data X (Left - Right)

   if (mp[2] !=0)
   {
      yValueTemp=(mp[2]*5.24f);

      if (yValueTemp>=480)
         mapPosition.y=yValueTemp/2;  // Move map by sensor data Y (Up - Down)
      else
         mapPosition.y=yValueTemp+262;
   }

   if (mp[1] !=0)
      mapPosition.z=-mp[1]*gyroCalibrationBasedDistance; // Zoom map by sensor data Z

   if (IsImmersive)
      map.transform.position=mapPosition;

}else if (item.Key.Equals("Sensor2"))
{
   for (int i=0;i<3;i++)   // Get Data from Sensor 2 X,Y,Z
      s2[i]=(float)item.Value.packets[lastPacketIndex].Data[i];
}
```

Figure 53 OSC listener function code

On the mobile application, a log procedure runs during the entire process to record the position and orientation of the phone and the user's head. Figure 54 shows the log function and format.



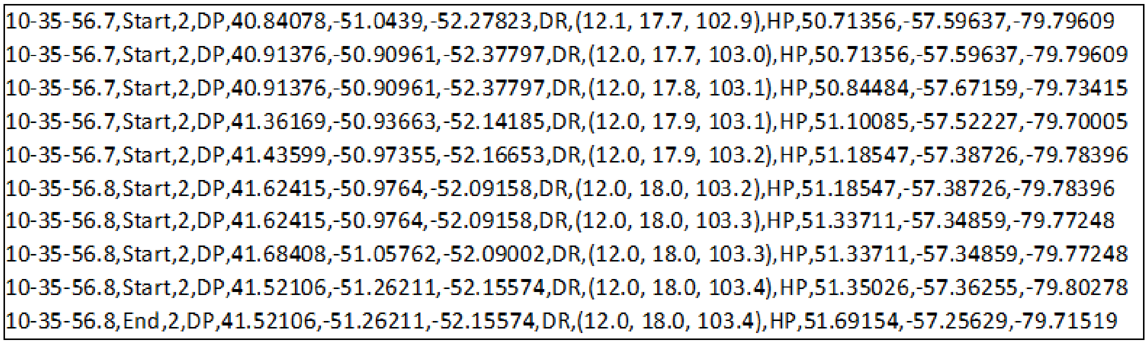
```
if (!File.Exists(fileName))
{
   File.Create(fileName);
   TextWriter tw = new StreamWriter(fileName);
   tw.WriteLine("File Created ");
   tw.Close();

}else if (File.Exists(fileName))
{
   TextWriter tw = new StreamWriter(fileName, true);
   tw.WriteLine(System.DateTime.Now.ToString ("hh-mm-ss.f")+
                 ","+startButtonPressed+
                 ","+condition+
                 ",DP,"+s1[0]+","+s1[1]+","+s1[2]+              // Device Position
                 ",DR,"+Camera.main.transform.eulerAngles+         // Device Orientation
                 ",HP,"+s2[0]+","+s2[1]+","+s2[2]               // Head Position
                 );
   tw.Close();
}
```

Figure 54 Mobile application log function code

The comma separated values (CSV) format (supported by Microsoft Excel) was used for logging. Each record is a row, and the value of each cell is equal to the values between commas. The data recording speed was 5-8 fps. Table 20 shows the log format.

Time (h:m:s.ms)	Status (Start/End)	Task #	DP	Device position (x,y,z)	DR	Device orientation (y,p,r)	HP	Head position (x,y,z)

Table 20 The format of the mobile application logger



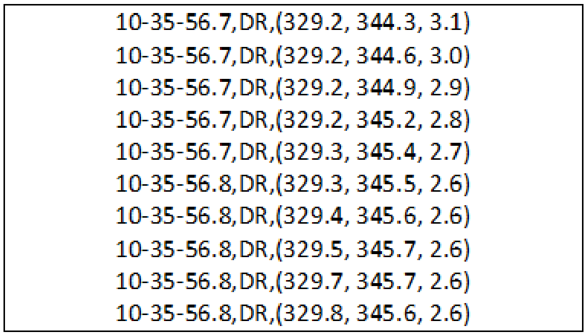
```
10-35-56.7,Start,2,DP,40.84078,-51.0439,-52.27823,DR,(12.1, 17.7, 102.9),HP,50.71356,-57.59637,-79.79609
10-35-56.7,Start,2,DP,40.91376,-50.90961,-52.37797,DR,(12.0, 17.7, 103.0),HP,50.71356,-57.59637,-79.79609
10-35-56.7,Start,2,DP,40.91376,-50.90961,-52.37797,DR,(12.0, 17.8, 103.1),HP,50.84484,-57.67159,-79.73415
10-35-56.7,Start,2,DP,41.36169,-50.93663,-52.14185,DR,(12.0, 17.9, 103.1),HP,51.10085,-57.52227,-79.70005
10-35-56.7,Start,2,DP,41.43599,-50.97355,-52.16653,DR,(12.0, 17.9, 103.2),HP,51.18547,-57.38726,-79.78396
10-35-56.8,Start,2,DP,41.62415,-50.9764,-52.09158,DR,(12.0, 18.0, 103.2),HP,51.18547,-57.38726,-79.78396
10-35-56.8,Start,2,DP,41.62415,-50.9764,-52.09158,DR,(12.0, 18.0, 103.3),HP,51.33711,-57.34859,-79.77248
10-35-56.8,Start,2,DP,41.68408,-51.05762,-52.09002,DR,(12.0, 18.0, 103.3),HP,51.33711,-57.34859,-79.77248
10-35-56.8,Start,2,DP,41.52106,-51.26211,-52.15574,DR,(12.0, 18.0, 103.4),HP,51.35026,-57.36255,-79.80278
10-35-56.8,End,2,DP,41.52106,-51.26211,-52.15574,DR,(12.0, 18.0, 103.4),HP,51.69154,-57.25629,-79.71519
```

Figure 55 Sample of mobile application log in CSV format

We tried to obtain the user's head orientation using the Polhemus device, but due to the lab environment the sensor's orientation data was not correct, so we attached another phone on the back of the user's head to use its gyroscope sensor for tracking the user's head orientation. We logged the orientation data from the phone attached to the head using the same time format as the first phone, so the two files could be merged.

Time (h:m:s.ms)	Device orientation (y,p,r)

Table 21 The format of the mobile application logger for the phone on the participant's head



```
10-35-56.7,DR,(329.2, 344.3, 3.1)
10-35-56.7,DR,(329.2, 344.6, 3.0)
10-35-56.7,DR,(329.2, 344.9, 2.9)
10-35-56.7,DR,(329.2, 345.2, 2.8)
10-35-56.7,DR,(329.3, 345.4, 2.7)
10-35-56.8,DR,(329.3, 345.5, 2.6)
10-35-56.8,DR,(329.4, 345.6, 2.6)
10-35-56.8,DR,(329.5, 345.7, 2.6)
10-35-56.8,DR,(329.7, 345.7, 2.6)
10-35-56.8,DR,(329.8, 345.6, 2.6)
```

Figure 56 Sample of the log from the phone attached to the participant's head

Our attempts to create the mF+C experience involved creating a user experience in IMS in which the phone screen operated much like a piece of glass overlaid on the projected context. To achieve a true immersive lens, we identified several variables such as the user's head position and orientation, the phone position and orientation, the distance between the user's head and phone, and the distance between the phone and the screen. Based on the identified variables, we developed an application for which results were fine in the initial position, but in some situations, they were incorrect. Therefore, we reviewed the algorithm and realized that a true immersive lens function is not based on head orientation alone, but rather the user's head position relative to the phone's screen position and orientation. We made a mockup of a system that incorporated these variables, but in testing we found that sensors were not operating reliably because of the noisy operating environment (to be discussed later). Moreover, while even 1 degree or 1 cm error has an impact on the final results, geometric calculations must be very accurate.

Finally, we decided to evaluate a more limited mockup in the user study, and leave evaluation of a true immersive lens for future work. The version we used in the study does not update the detail view on the phone according to the user's viewing distance and angle, only the position and orientation of the phone itself.

4.4 User Study Procedure

4.4.1 System Setup

To setup the system for running the user study we used an NEC U300X Ultra short throw lens (0.377:1 throw ratio, 3100 lumens)[15] projector with 80 centimeters distance from the wall to a have 92 inches (diagonal) screen. We put the Polhemus source on top of the projector with an 80 cm distance from the wall and marked the walking area in front of the projection area with a green tape (Figure 59). The PC was connected to the projector with an HDMI cable. A GoPro[16] headband was used to attach a sensor for user's head tracking. One Polhemus sensor was connected to the front part of the headband.

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[15] www.necdisplay.com/p/multimedia-projectors/np-u300x?type=support

[16] www.gopro.com

Figure 57 NEC U300X Projector (left) Side view of user interaction area (right)

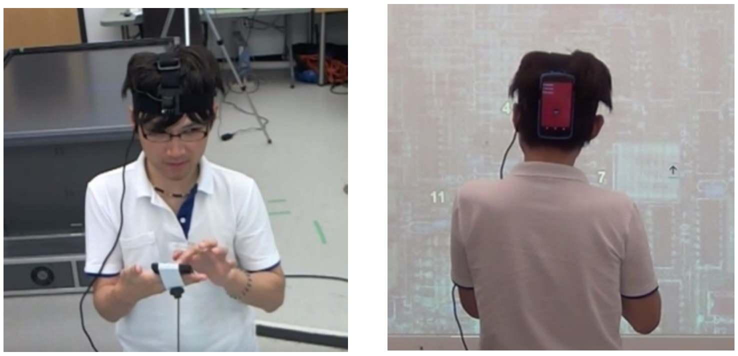


Figure 58 Sensors Location: Front view (left) back view (right)

A mobile case with a Nexus4 mobile phone was fixed to the back of the headband. Another sensor was attached by a rubber ribbon to the back of the mobile phone for tracking the phone's location (Figure 58).

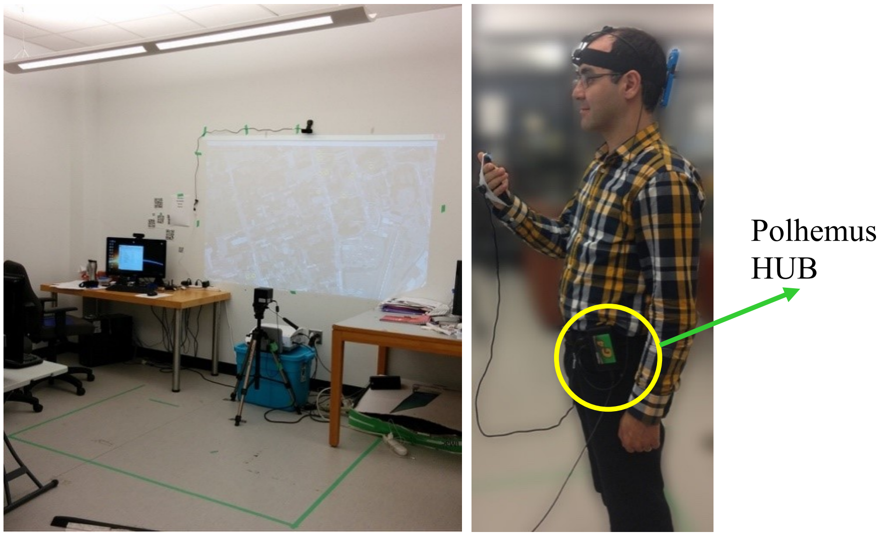


Figure 59 Setup system: Projection area (left) User side view (right)

Both sensors were connected to the Polhemus Hub, which was attached to the user's pocket or belt. The hub operates with USB cable or wirelessly. Because of the lag in the wireless mode, we connected the hub to the PC with a USB cable. During the study, all the lab lights were ON, and two cameras were recording the entire study from the front and back angles.

4.4.2 The Study Protocol

1- Participants were selected by sending the recruitment notice to different faculty e-mail lists, specifically Engineering, Science, Architecture and Planning, Management, Computer Science, and Medicine.

2- We arranged the schedule for selected participants using Doodle web application

3- At the beginning of the study, we informed participants that the entire study would be recorded by two cameras.

4- We asked participants to read and sign the consent form and fill out the background questionnaire.

5- We had one trial task that took about 1-2 minutes to introduce each method. In the trial task, participants were briefed on how the system works and how they have to put their fingers in between the sensor and phone. A picture of a building was projected, and they were free to use the system and ask questions of how the system works. The trial task let the participants get familiar with the system and methods, but not the conditions and types of tasks.

6- Participants could rest for 1-2 minutes between tasks

7- After all tasks were completed for a method (IMS, SBS, SWP and PhoneOnly), participants filled out a post-method questionnaire. Performing each task took about 3-5 minutes. Participants usually completed questionnaires in less than 2 minutes.

8- At the end of the study, participants answered a few questions as a short interview, which took about 4-6 minutes.

9- Participants received compensation and signed the compensation form.

In total, the study took about an hour and a half to complete for each participant.

4.4.3 Data Collection

To answer the research questions in this study, we found that measuring the time of each task could help us to know about user behavior for each method quantitatively. We can also understand the relation between time in different types of pictures and conditions. We collected data before, during and after tasks by using diverse methods (see Table 22). Most of the measuring instruments are available in the appendices section.

Instrument	Description
Background Questionnaire	Demographic
Observation Notes	Hand-written notes about the participants' behaviors by researcher
Tasks Answer sheet	Evaluation tasks questions regarding participant's answer in True/False format by researcher
Video	Video recordings of participant behavior while performing the tasks
Logging Data	Time, mobile phone and participant's head position and orientation, and task number and status in 5-8fps.
Post-method Questionnaire	Participants' answers in regards to each method in Likert scale
Interview	Participants' explanations about their overall experience, feedback about the techniques used in each task, and any other comments

Table 22 List of data collection instruments

4.4.4 Participants

For this user study, we tried our best to recruit a varied sample of participants. This diversity could allow us to gather a set of opinions about mF+C and mitigate the impact of specific background knowledge or skills on the results. We recruited 36 participants (13 females and 23 male) including students, faculty members, and staff. The average age of participants was 30 years (18-66). We recruited 12 undergrads, 16 graduate and eight staff/faculty from Computer Science (11), Engineering (8), Science (10) and other disciplines (7). The number of Android phone users and iPhone users were the same (17), and two participants used BlackBerry phones. All participants were familiar with at least one smartphone. Whereas 13 participants were using their smartphone for more than 4 hours a day, 17 participants were spending 2-4 hours on their phone, and for six of them, this time was less than 2 hours. All participants had experience using, at least, one of the mobile map applications such as Google Map, Apple map, MapMyFitness, Bus/Train Map, Offline navigation applications or others. All participants were familiar with one of the zooming technique on the phone such as tap, double tap or pinch; they also had the experience of using, at least, one of the mobile phone sensors such as GPS, Compass, Gyroscope, NFC, Fingerprint, Proximity, Magnetic, Accelerometer, Pressure or Light. While 27 participants used their personal phone for a specific task that was related to their job, two of them did not prefer to use their personal phone, but they might have used their personal device for their job if they would not have had any other choice, and seven participants had never used their device for their job. Seventeen participants were using their phone as a remote controller, such as TV remote, presentation remote or music controller. The participants attended individually, and it took about 1 hour and 30 minutes for each one to finish the study. $20 was paid as compensation to each participant.

4.5 Data Analysis

After the study, we used the responses to the post-method questionnaires, shown in Table 23, to analyze the user preference and satisfaction about each method of interaction.

1	It was easy to use the application
2	The information provided on the phone was accurate and properly aligned with the projected image.
3	The application worked in real time, without noticeable lags.
4	I sometimes lost track of my current location
5	The distance between the projection and the mobile device was acceptable
6	This method was easy to use
7	I felt physical discomfort during these tasks
8	Finding target objects was easy using this interaction technique

Table 23 List of questions in post-method questionnaire

For each method, the amount of physical discomfort and the satisfaction of the distance between the phone and the screen could be obtained from the survey responses. We used time logs and task answer sheets for each user to calculate the time for performing the tasks, and we used the camera video to observe the participant's behavior. For example, we counted the number of the times that a participant switches their attention between Focus and Context and the amount of the time looking at Context vs. Focus. The observation notes and interviews were used to give context to and resolve ambiguities in the survey responses. From the video, we found that in many cases for switching between focus and context, participants just turn their eyes instead of their head; therefore, the head orientation information was not used to determine context switching. Instead, the video was coded for attention switches.

During each task, we asked participants 1-6 questions, and they were supposed to find answers by looking at the projected picture and/or using the phone or a combination of both.

1	Overall, what was your experience interacting with linked projected content and mobile phone detail?
2	Did you find any difference between map and board?
3	How was the distance between you and projection?
4	Which method was your favorite? Which one did you like better?
5	Do you have any suggestions to help make any of these methods more useful?
6	Do you believe the techniques could be useful in your work? If so, how? If not, why not?

Table 24 List of interview questions

At the end of the study, we asked participants some questions as a short interview, listed in Table 24. The participant responses were used to provide context for quantitative observations and post-method questionnaire analyses.

CHAPTER 5 RESULTS

In this chapter, we present our analysis of the collected data from the user study to address the research questions and objectives, which are listed below:

- How does content familiarity affect an mF+C system?
- Does providing details on the phone screen adequately compensate for poor context visibility due to projecting on non-planar, non-uniform surfaces?
- What are the strengths and weaknesses of the three focus + context linking techniques (Immersive, Side-by-Side, and Swipe)?

Table 25 represents the expected time that was calculated by using the described model in the study design chapter, the average time that participants spent for each task during the user study, and the ratio between expected time and average time. In all figures and tables, the unit of time is in seconds, and the unit of displacement (e.g. x-y) is in centimeters.

Format	Task	Expected Time	AVG Time	Ratio
O-Map	Name of 10 restaurants	39.95	74.71	53%
O-Board	Board with RED and Yellow Connectors	98.20	177.55	55%
O-Map	Name of Location marked 1-5	39.05	68.86	57%
O-Board	Positive-Voltage Supply	94.08	154.62	61%
O-Map	Start-Endpoint street and websites	107.13	184.58	58%
O-Board	DDR 3 Memory	75.60	123.32	61%
SO-Map	Name of Streets 1-6	51.00	86.21	59%
SO-Board	BOX of colors, LEDs	155.95	264.10	59%
SO-Map	Raymond Field	64.75	99.54	63%
SO-Board	Resistor marked by 1	72.20	129.49	56%
SO-Map	Subway Map	86.55	148.53	58%
SO-Board	11 markers on board	72.92	143.26	52%

Table 25 List of expected time, average time that participants spent on tasks and ratio between expected and average time

As we can see, there is a range of 52% to 63% between expected times and average times for tasks, which shows that the expected time, while a significant overestimate, is related to the average time.

5.1 Familiarity with content type

To find the effect of familiarity with content type on an mF+C system, we calculated the average time for both Map and Board pictures. During the interviews, we asked the participants which type of picture was easier to find the answers. Twenty-four participants said that working on the map was easier than the board (see Figure 60). With a chi-square test we found there was significant difference between the type of contents, (χ^2 (1, N=26) = 16.96, $p<0.001$). Therefore, the result confirms the selection of these two types of pictures as representatives of familiar vs. unfamiliar content types.

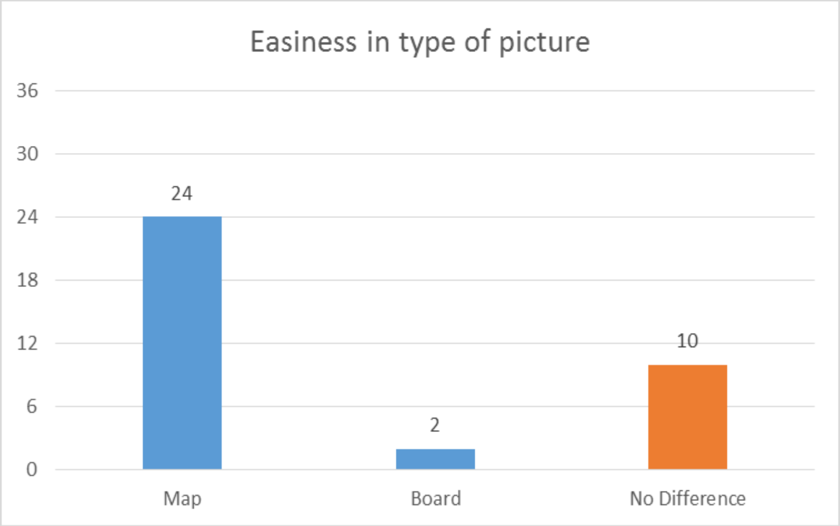


Figure 60 Number of participants who selected which type of picture was easier

We compared the time that 36 participants spent for ten tasks in two sets (6 Map, 4 Board) that were described in Chapter 4 when the time completion complexity was similar between both sets (Map 388.43 vs. Board 376.67). We assumed that all participants with computer science, computer engineer and electronic engineer background are familiar with electronic boards and components. In this study, 17 participants were familiar or had a background knowledge of the electronic boards. We analyzed the data for two sets, one for participants who are familiar with the electronic boards (the "Familiar") and another one for those who do not have any knowledge about the electronic boards (the "Unfamiliar").

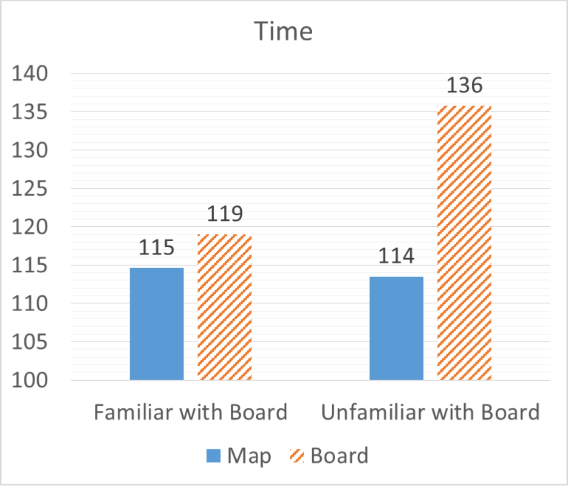


Figure 61 Average of Time for familiarity with type of contents

According to Figure 61, there is a difference in time between Map and Board on both Familiar and Unfamiliar. The statistical test results are presented in Table 26.

		Map	Board	ANOVA test
Time	Familiar	Mean=115	Mean=119	*F(1,145)=0.21, p=0.6*
	Unfamiliar	Mean=114	Mean=136	*F(1,165)=6.76, p=0.01*

Table 26 Stats for test the effect of familiarity with type of pictures

As we can see on Table 26, Familiar and Unfamiliar spent the same amount of time on the map. As a result, with less time the participants who were familiar with electronic boards performed the tasks better than who were not familiar with the boards, so the results show that the familiarity with content type has direct impact on improving the performance, particularly on task completion time.

5.2 Conditions Evaluation

Because the tasks and images used in optimal vs. suboptimal conditions were different, to better evaluate how environmental effects (impacting the visibility of the projected image) are important in task performance, time for each task were recorded for all participants in all methods and conditions.

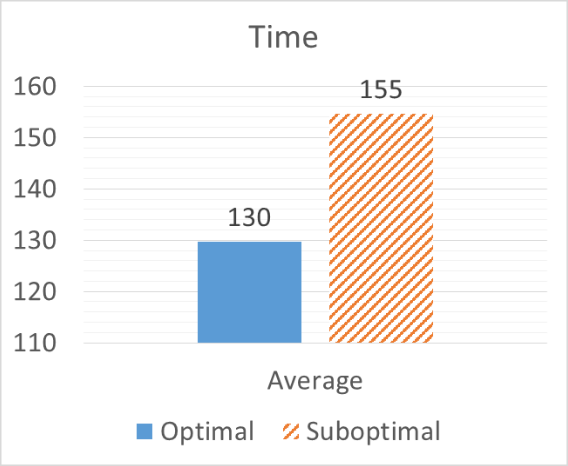


Figure 62 Average total Time to complete a task in both Optimal and Suboptimal conditions

The bar chart on Figure 62 depicts the average total time of performing tasks in different conditions. To evaluate this, we selected 11 tasks in two sets (6 Optimal, 5 Suboptimal) with similar time (445.65 vs. 444.65). Note that this is almost the entire task set, minus one in the suboptimal conditions. Since per-method averages are reported in Figure 65, including the extra Suboptimal task this does not significantly impact the comparison. As it is clear from the bar chart, participants finished tasks in less time in the optimal conditions than the suboptimal conditions. An ANOVA test result show that there is a significant difference in Time between Optimal and Suboptimal conditions *(F(1,382)=12.44, p<0.001)*.

We measured the number of times a user's eyes switched between the mobile phone screen and the projected screen for all 12 tasks for 36 participants by watching the recorded videos with a front camera and using a simple JavaScript application for coding. While the application and the video player were running, by pressing two buttons (F for mobile phone, and C for projection) the application logged the time between two events, which were looking at the phone screen (focus) or projected screen (context), and finally the total number of each event was listed in a table.

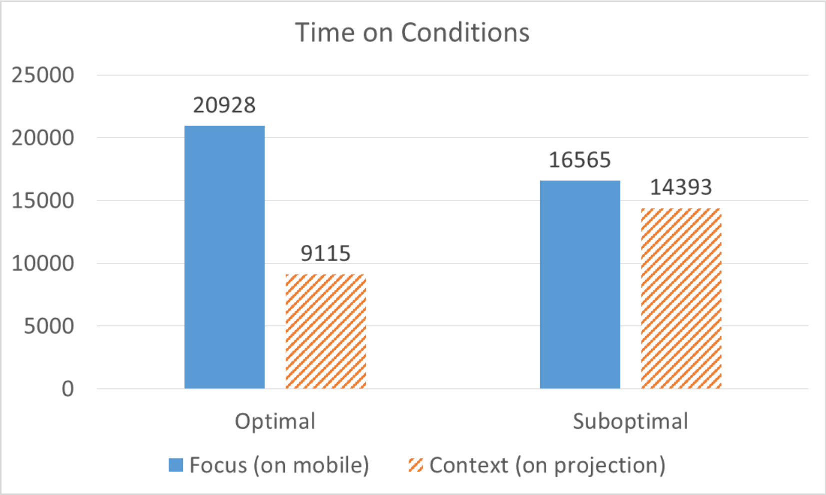


Figure 63 Total time participants spent on Focus/Context in different Conditions on all tasks that are selected for conditions comparison

The bar chart in Figure 63 shows that participants spent more time on the mobile screen (Focus) than the projection area (Context) in both optimal and suboptimal conditions; however, in the optimal condition participants spent 37% less on context compared to with the suboptimal. In the suboptimal condition, during video coding we found the participants spent time on the map to find something (e.g. a marker) as a guide that they can match with the phone screen data. To put it briefly, results show that environmental conditions were important for the time of interaction with a phone and a large display.

5.3 Methods Evaluation

In this section, we are presenting the collected data to evaluate the methods, which were used in the user study obtained by system logs and user responses to the post-method questionnaires and interviews.

5.3.1 Methods Time Evaluation

To evaluate and compare strengthens and weakness of methods, we used system logs which include the average Time for each method. The results are illustrated in Figure 64, collected from the mobile application and task responses from all 36 participants. The time were logged by pressing the Start button until the end of the task which was the time that End button was touched.

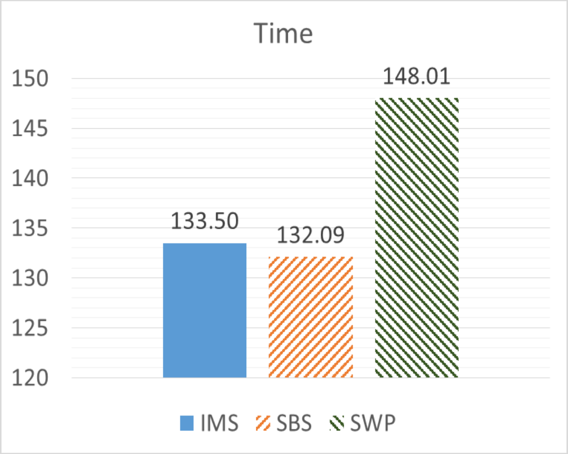


Figure 64 Average of Time for Methods

As we can see, participants spent similar time on IMS (Mean: 133.5 SD: 64.9) and SBS (Mean: 132.1 SD: 71.73), but with a t-test we found the time that was spent on SWP (Mean: 148 SD: 68.3) had a significant difference with IMS (t (276) = 1.81, p=0.03) and SBS (t (277) = 1.9, p=0.02) methods.

The results show that the SWP method takes longer without considering the environmental effects. It is important to consider how mF+C methods work in different conditions.

5.3.2 Methods in projection conditions evaluation

To be able to evaluate how an mF+C system works in different environmental conditions, and also to compare the advantages and disadvantages of each of three methods, we measured Time for IMS, SBS and SWP in both Optimal and Suboptimal conditions for all participants. We used system logs to collect the time between the start and the end of each task for two groups of tasks, six optimal and five suboptimal, with a similar expected total time in each group, calculated using a modified KLM assessment as discussed in the previous chapter.

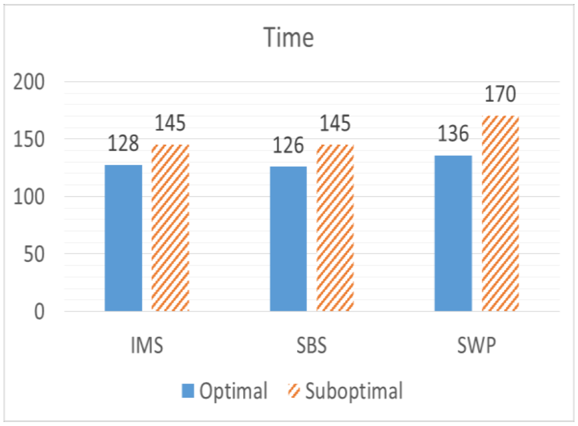


Figure 65 Average of Time for Methods in each Optimal and Suboptimal conditions

Figure 65 represents the time for optimal and suboptimal conditions for IMS, SBS and SWP methods. As we can see, participants spent similar time using IMS and SBS on both optimal and suboptimal conditions; however, they spent at least 6% more time in optimal and 17% more time in suboptimal conditions on SWP. In IMS, finding the answer is completely related to the device position and orientation, but in SBS, the answer is directly related to the pointer's location.

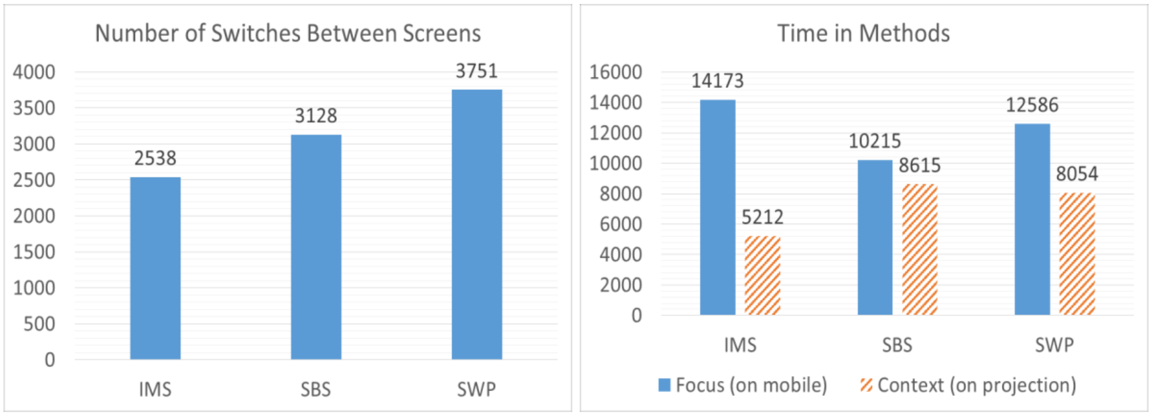


Figure 66 (left) Number of times users switched his attention between two screens in each method for all tasks (right) Amount of time on Focus/Context for each method

Figure 66 (left) shows the number of times participants switched their attention between Mobile screen and projection Content. As we can see, in IMS participants switched between screens 18.8% less than SBS *($F(1,283)=4.32$, $p=0.03$)* and 32.3% less than SWP *($F(1,281)=16.5$, $p< 0.001$)*. It shows that, in IMS a user needs to switch between two screens fewer times. This might be because of the quick matching between the focus and the context. To compare with SBS and SWP, in IMS a user does not need to go back and forth many times to check whether the pointer in the context, or the projected picture is in the right place and whether the corresponding data is available on the phone or not. With an ANOVA test, we found there was also a significant difference between SBS and SWP *(F(1,280)=4.27, p=0.039).* Obviously, participants spent more time (Figure 66-right) on the mobile phone screen (Focus) than the projected picture (Context) in all methods; however, in IMS user spent time 39.5% less than SBS and 35.2% less than SWP on the projected picture. In SBS, a user needs to control the location of pointer, in SWP a user should control the location of the projected picture, so they have to spent time on the Context. In IMS the Overview is in a fixed place behind the Focus device, and while the user knows that the Focus data is related to the phone position and orientation, most of their attention is on finding the answer of the question rather than trying to match the Focus and Context. In summary, we believe that the IMS method is less dependent on Overview visibility.

5.3.3 Methods in task type categories

To consider how the interaction methods worked in certain types of tasks, we evaluated all methods in one task of four different categories. We deeply reviewed the users' behavior for 6 selected participants and observed their unexpected actions while performing the tasks. We compared the participants task completion time and interactions with the expected time and operations that we calculated using the adapted KLM model described in chapter 4.

The first task is from the category of "Finding based on shape-colors".

Figure 67 "Board with Red and Yellow Connectors" Task

In this task (Figure 67), we asked participants to count the number of red and yellow jumpers, read the serial number of one of the four similar electronic chips, the revision number of the board, the name of company who made the largest chip, and the text on the white component.

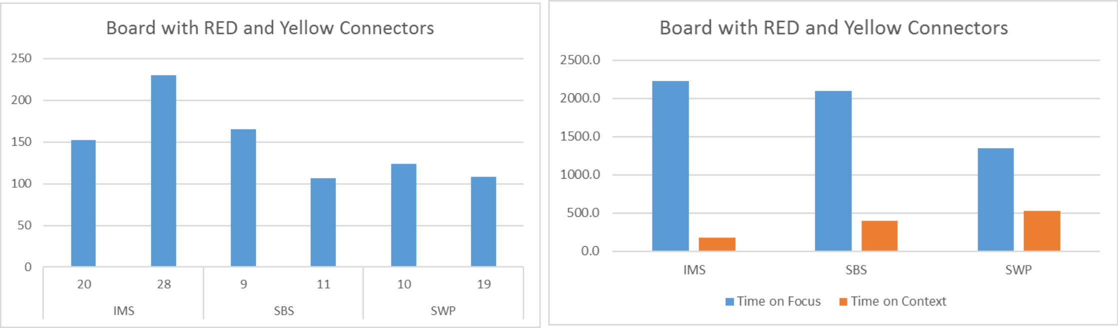


Figure 68 Time completion of tasks for selected participants in "Board with Red and Yellow Connectors"

Figure 68-left shows the time to complete each task for six selected participants. Based on our KLM expected time for SWP method, this task should be done in 96.7 seconds.

P19's time was close to the expected time: he spent 108 seconds to finish this task. Most of this extra time was spent visually scanning the context image. In Q2 (yellow jumpers) P19 started to search the map by moving the viewfinder seemingly randomly around the context for 13 seconds and then he said "4 yellow". P19 saved time in later questions by starting to search as the question was being asked and navigating directly to the target. For example, Q3 and Q4 were completed 2 and 4 seconds less than expected, respectively. Anticipatory navigation lead to extra time for Q5. The answer to Q5 was visible by looking at the context and it was also in the same location as Q4, so we predicted 2 seconds answer. P19 moved the context immediately, and took 6 seconds to return to the location and read the answer. Perhaps because of the familarity built up with the context in this region for Q5, and because of the small visible area in the overview, Q6 was answered almost immediately after it was asked (1sec actual vs. 4.1 secs expected).

User P19	
Q1: 23 sec, two times search entire map Read: 1sec	Q1: A+G(1)+Q1(4.4)+M(1.35)+S(23)+R(1) =30.75
Q2: User asked question: which connector, 1 sec We repeated “Yellow”: 1 sec Search entire map: 14 sec Read: 1 sec	Q2: G(1)+Q2(4.4)+M(1.35)+Error(2)+S(14)+R(1) =24.75
Q3: during the question he moved the picture:4 sec Read: 1 sec	Q3: G(1)+Q3(11)+M(1.35)+SP(4)+R(1) =18.35
Q4: Search+Point+read=4 sec	Q4: G(1)+Q4(4)+M(1.35)+SPR(4)=10.35
Q5: Search+Point+read=6 sec	Q5: G(1)+Q5(4)+M(1.35)+SPR(6)=12.35
Q6: during the question, he moved picture to the right place Read: 1 sec End: 2 sec	Q6: G(1)+Q6(6)+M(1.35)+SPR(1)+E(2) =11.35
Time: 30.75+24.75+18.35+10.35+12.35+11.35= 107.9	

With the exception of Q1, P10 finished the task using SWP in a manner and time close to expected. P10 spent 41 seconds to find the answer in Q1. Starting by looking at the context only, he found the location of the red jumpers, and after 10 seconds he said that the number of red jumpers are 2. But he then pointed to the phone screen and seeing the detail asked “do I have to count each one ?” He then used the focus to count individual jumpers.

P20 performed this task using the IMS method and finished it in 152 seconds, which was 53 seconds longer than the expected time (99.2 seconds). This was due to longer than expected visual searching, asking for question clarification, and longer time counting jumpers in the lower-right cluster using the detail view. In question 2 the jumpers were visible on the context view but P20 used the focus view mainly and spent 20 seconds rather than the expected 7 seconds, since visually scanning using the focus requires looking at the focus and ensuring that he is covering the desired area of the context when searching. This behaviour continued in subsequent questions.

P28 spent 230 seconds on this task using IMS: 131 seconds longer than the expected time. Much of this time was spent searching the diagram (15 seconds in Q1, 80 seconds in Q2, 40 seconds in Q3). P28 was not methodical in their method of searching the context, seeming to move in a random pattern. In Q2 for example, he searched the entire map three times. On two occasions he was very close to the location of the answer, but suddenly changed direction. Despite this randomness, the participant seemed to move the focus device very slowly, being careful how they tilted it in relation to the projection.

For the SBS method, the expected time for this task was calculated to be 98.7 seconds using our adapted KLM. P11 was very close to this, taking 107 seconds. This participant's behaviour was also closely modelled by the KLM estimate.

P9 also used SBS, but took 165 seconds. Some of this time was due to using the software zoom feature: he took 30 seconds rather than the expected 15 for Q1 as he zoomed out and couldn't count the jumpers, then returned to the normal zoom level to answer the question. For the second question, he used the focus rather than the context for visual search, taking twice as long as expected; he repeated this behaviour for Q4.

We believe that in the tasks that users have to search on the map and they are not dependent to the context, because there are no guides on overview or the overview is noisy, they prefer to use the focus device which contains more legible and identifiable data.

In addition, because of the order of questions, in SBS and SWP, when users found the answers, they did not change the location of the marker or projection before the next question, but in IMS both participants rapidly returned to the initial position at the center of the projection after the answer was found. In general, this meant that if several questions were in the same region, minimal interaction was required in SBS and SWP. In IMS for questions one, two and four both participants searched the entire map to find the answers using focus device. In this task, the targets for the last three questions were very close to each other, so in SBS and SWP the participants found the answer through small movements on the phone and saved time. We had five white components on the picture, but only one of them had text on it. In IMS and SBS, when the overview of the picture was visible, participants looked on the context to see which component has text, but in SWP, because of the previous question, only two white components were visible in the projection and the component with text was exactly in front of the participants, so it was easy to find the answer. We found therefore that the order of questions has an impact on performance.

Figure 68-right bar chart shows the amount of time that these 6 participants used the focus vs. context. Since the answer to each question was based on searching for colors and shapes, this task was not dependent on seeing information that was only presented on the context. Even so, the context had enough data to find the location of a question's target for at least 4 of 6 cases, since the colours and shapes were visually distinguishable using the context alone. It might be true that IMS is easier to use because of the fast responsiveness to user interaction, but it seems that it also depends on the task, since the context might have enough useful data which can help participants use the focus device only when absolutely needed. In addition, when relevant details are in close proximity to each other, the stable relationship between focus and context in SBS and SWP can be an advantage.

The second task that we evaluate for how participants used the interaction methods is finding answer of questions based on position and natural features on the projection.

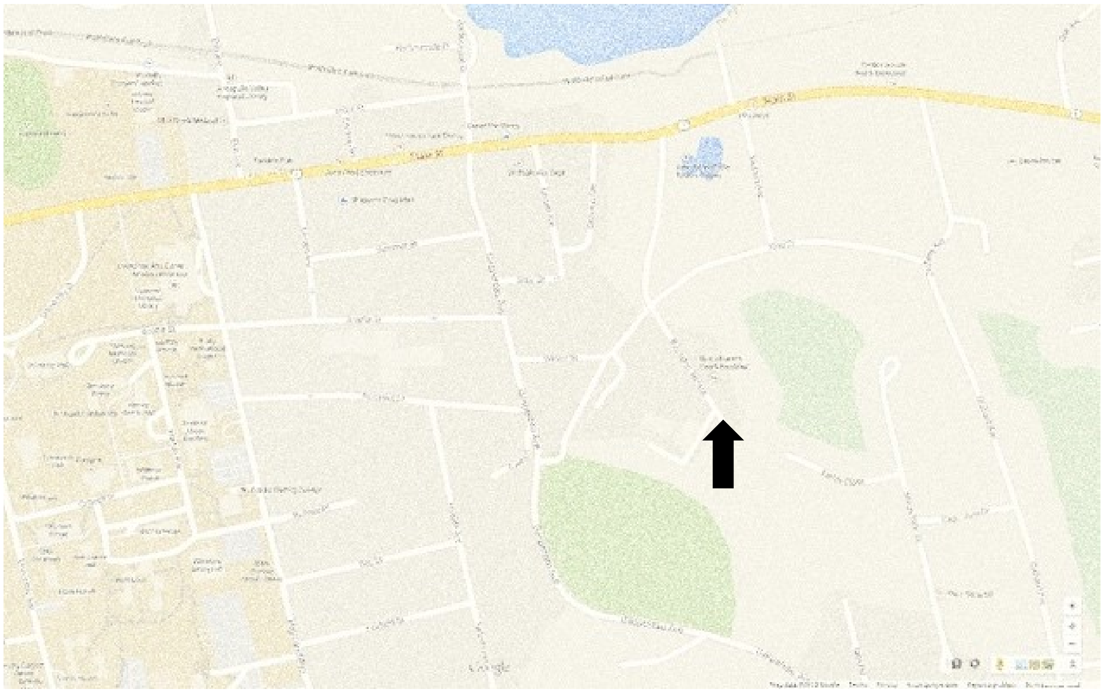


Figure 69 "Raymond Field" Task

In this task (Figure 69) we asked participants to find the name of the field located on the top-left side of the map, the name of the library that marked with a library icon, the name of the town located near the edge of a small lake, the name of the restaurant at the bottom-right side of the map, and the location marked on the surface with an up-arrow.

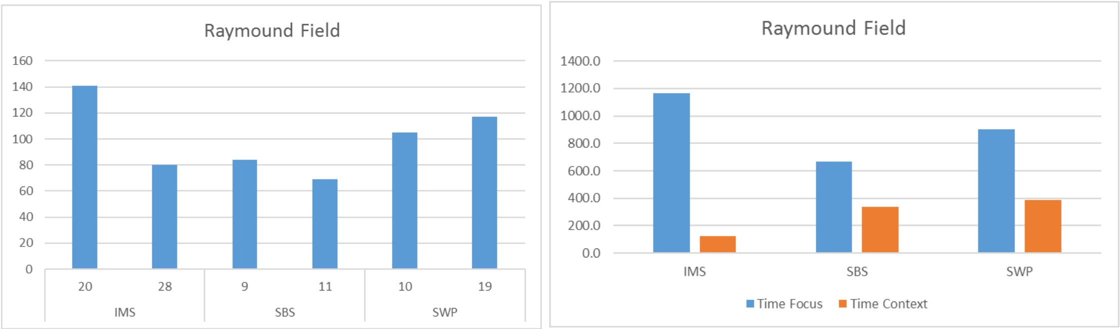


Figure 70 Task completion time for selected participants in "Raymond Field"

Figure 70-left shows the time taken for this task for six selected participants.

Our KLM expected time for the SWP method is 66.15 seconds. P19 finished this task in 117 seconds, which was 50 seconds more than the expected time. This was due mainly to spending 44 seconds visually scanning the context for the library icon and an additional 17 seconds looking for it using the focus device. There was only one library marked with an icon on the map, but P19 did find another library and asked “this library?”, then continued to search when told the target had an icon. This is an example of the difficulty one might encounter when relying on the context to search for less conspicuous items.

User P19	
Q1: User asked question “ the field?”: 1 sec Search: 1sec Point: 5 sec Read: 1 sec	Q1: A+G(1)+Q1(4.4)+M(1.35)+Error(1)+S(1)+P(5)+R(1) =14.75
Q2: Search entire map: 42 sec Found library without icon and asked “this library?”: 1 sec We said “no, the library that has icon”: 2 sec Search: 11 sec Read: 1 sec	Q2: G(1)+Q2(2)+M(1.35)+S(42)+Error(3)+S(11)+R(1) =61.35
Q3: Point: 7 sec Read: 1 sec	Q3: G(1)+Q3(5)+M(1.35)+SP(7)+R(1)=15.35
Q4: Point: 4 sec Read: 1 sec	Q4: G(1)+Q4(4.1)+M(1.35)+SP(4)+R(1)=11.45
Q5: Point: 6 sec Read: 1 sec End: 2 sec	Q5: G(1)+Q5(2.9)+M(1.35)+SP(6)+R(1)+E(2)=14.25
Time: 14.75+61.35+15.35+11.45+14.25=117.15	

P10 spent 107 seconds vs. the expected 66.15 seconds on this task using the SWP method. In this case, visually scanning the context to find the library icon took 12 seconds more than the expected time. P10 was 2-3 seconds slower than our expected for all questions in controlling the viewfinder. Possibly due to difficulty using the interface, P10 tried to use the context, for example to read the name of the restaurant in Q4, and only turning to the focus device when unsuccessful, adding to the task time.

P28 spent 80 seconds on this task using IMS: this was close to expected (16 seconds over, due mainly to asking for clarification and explaining their answer to Q3). P20 also used IMS but took141 seconds, which was 77 seconds longer than expected. The library question was answered quickly, but he was confused about the lake question (Q2), which took 65 seconds to answer. The remaining questions were answered efficiently.

Using SBS, P11’s interactions were close to the expected in our KLM. P9’s behaviour was different: with the exception of Q2, P9 found the target locations by visually scanning the context only. In question 2, he quickly searched the context and he said that “I can’t see the library icon here” and then traced the whole map using the focus device, taking 18 seconds. P9’s total time was 84 seconds, 20 seconds more than expected (64.15).

In this task, during using IMS method, because of the different questions, location of the answers, and visibility of the texts, participants required physical movement to find the answers. In addition, similar to the other tasks, in IMS, when both participants found the answer of each question, they came back to the initial position for the next question. While three out of five questions were located on the edge of the picture, in SWP method, for four questions, the overview of picture was missed, so after finding the answer of each question (except question 1), there was a noticable preparation time that participants spent to get the location of the next question. When the answer of the second question was very close to the first one, 2 of 4 participants in SBS and SWP found the answer quickly. While questions three to five were located on the right side of the map, there was no shifts between locations, and because of the picture on the phone was not related to the device orientation, the texts were clear enough to read, so user performed this task in SBS faster than IMS and SWP. There were two libraries on the map but only one of them had an icon, and our question was the name of library which was marked by library icon. When the library icon was not identifiable on the context, all participants just used the phone screen for that question. Answering to this question takes a longer time than our predicted time. Natural features, and position guides that we mentioned in this series of questions, (e.g. top-left, bottom-right), were causes that make the task less dependent to the context for at least 3 out of 5 questions, so same as previous task, in IMS user prefered to use the phone which provides clear picture than nosiy projected map, but in SBS and SWP, because the participants should control the location of the viewfinder or projected picture, they spent more time on context to compare with IMS (Figure 70-right).

The third task that we evaluated is from tracing category. In this task (Figure 71) we asked participants to follow the colored line and find the names that are connected by lines.

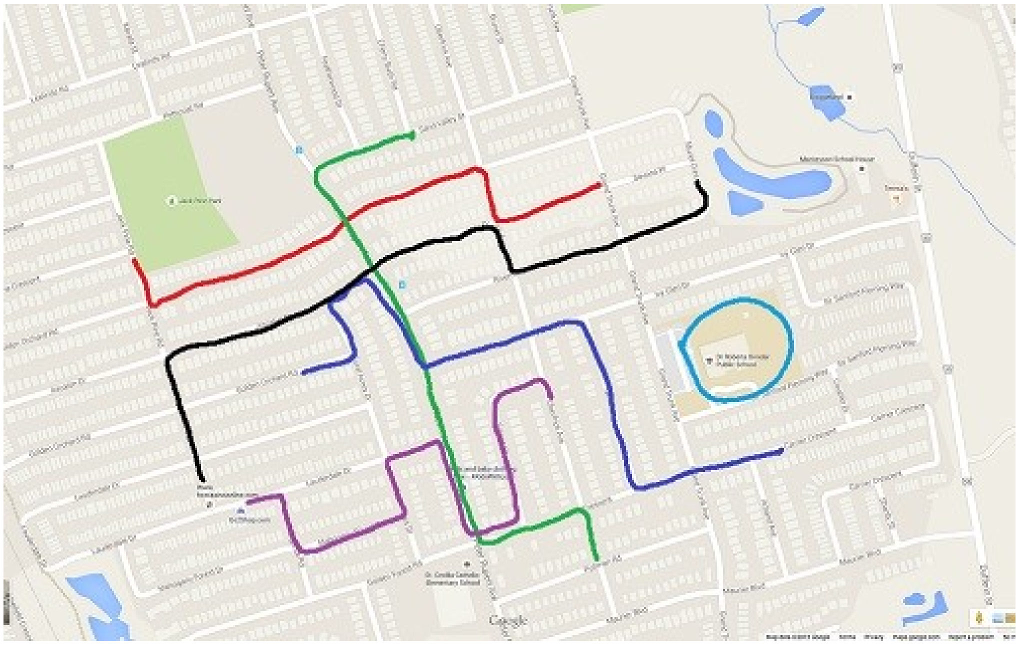


Figure 71 "Start-Endpoint street and websites" Task

The order of questions was important to make the task challenging. The last question was finding the name of school on the map. We highlighted one building with light-blue color but there was no question for that particular section.

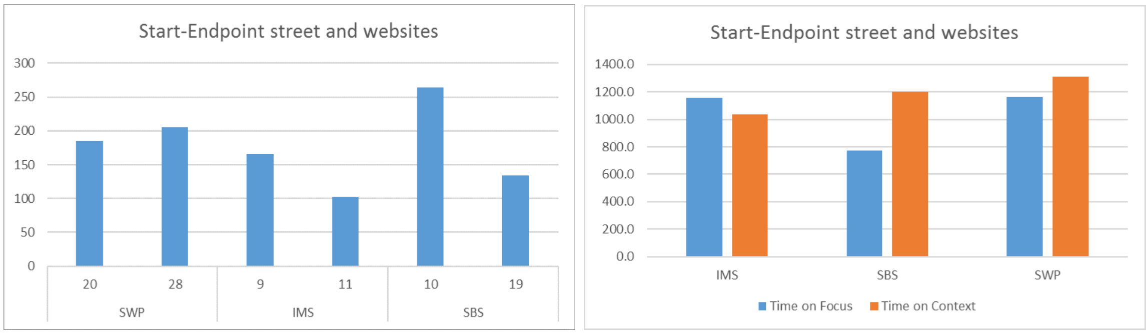


Figure 72 Time completion of tasks for selected participants in "Start-Endpoint street and websites"

Figure 72-left shows the time completion of each task for selected participants. We consider P19's behavior first. Based on our expected time for the SBS method, this task should be done in 115. 5 seconds, but P19 spent 134 seconds to finish it. P19 took longer than expected both to swipe and to locate targets: 6 seconds vs. 2 seconds for Q1, and 6 seconds vs. 1.5 seconds in Q4, and 13 seconds vs. 2.5 seconds in Q5. Additional time was taken asking for questions to be repeated and for more detail about the targets. P19's performance improved at the end of the task. The expected time for finding the location of

question 6 was 13 seconds, but while the question was being read he moved the viewfinder on the projection, so he took only 9 seconds, which was 4 seconds less than our predicted time in this question. We expected that participants would point to a circled building for the school name, and when they realized that it wasn't a school, they would search the entire map. However, P19 saw that the circled building was not a school, and visually scanned the context to see a candidate building on the bottom part of the map, then rapidly moved the viewfinder to get the answer.

User P19	
Q1: Question time: 6 sec Search-Point1: 6 sec Read: 2 sec Search-Point2: 4 sec Read: 1 sec	Q1: A+G(1)+Q1(6)+M(1.35)+SP1(6)+R(2) +SP2(4)+R(1) =21.35
Q2: Search-Point1: 3 sec Read: 2 sec Search-Point2: 6 sec Read: 2 sec	Q2: G(1)+Q2(4.2)+M(1.35)+SP1(3)+R(2) +SP2(6)+R(2) =19.55
Q3: User asked to repeat the question: 3 sec Search-Point1: 3 sec Read: 3 sec He was confused by question, we described: 3 sec Search-Point2: 4 sec Read: 2 sec	Q3: G(1)+Q3(4.4)+M(1.35)+Error(3)+SP1(3) +R(3) +Error(3)+SP2(4)+R(2) =24.75
Q4: User asked to repeat the question: 2 sec Search-Point1: 6 sec Read: 2 sec Search-Point2: 4 sec Read: 1 sec	Q4: G(1)+Q4(4.2)+M(1.35)+Error(2)+SP1(6) +R(2) +SP2(4)+R(1) =21.55
Q5: Search-Point1: 13 sec Read: 3 sec Search-Point2: 5 sec Read: 2 sec	Q5: G(1)+Q5(4.4)+M(1.35)+ SP1(13)+R(3) +SP2(5)+R(1) =28.75
Q6: Point to the highlighted: 5 sec Pointed to the answer: 4 sec End: 2 sec	Q6: G(1)+Q6(5)+M(1.35)+SP1(5)+SP2(4)+E(2) =18.35
Time: 21.35+19.55+24.75+21.55+28.75+18.35 = 134.3	

P10 performed the task in 264 seconds in SBS method which was 153 seconds more than our expected time. We expected 2 seconds for searching for and pointing to the target of Q1, but he spent 6 seconds reviewing the context, and took 25 seconds to put the viewfinder on one side of the red line. On two ocassions the viewfinder was over the target street name but during swiping he suddenly moved the viewfinder away. For the remaining questions P10 was generally very slow and cautious when swiping, perhaps to be sure that the pointer was located at the correct location. At the same time, the participant did not always carefully view the focus while locating a target. For example, the target location of question 4 was at the same position of the previous question, requiring just reviewing the focus screen and no swiping. However P10 rapidly moved the viewfinder at the start of the question and took 13 seconds move it back over the target. For Q6 (finding the school), P10 started moving the viewfinder and looking at the focus device, but after 10 seconds he switched to the context and tried to find the school by scanning from top-left to bottom right of the map. He saw the school after 15 seconds, then navigated the viewfinder over the school to be certain.

In SWP method, P20 spent 185 seconds to finish the task which was 62 seconds more than our expected time. In question 1, the participant identified the area of the target in 3 seconds but took 11 seconds to adjust the focus to the correct position so that he could read the answer. P20 took longer than expected when moving the focus for subsequent questions as well, including 2-3 seconds extra time for each due to difficulties controlling the projection. In Q6 P20 first moved the focus to the highlighted section, and upon realizing that it was not a school, he used the focus device to search the bottom side of the map, finding the school after 8 seconds.

P28 spent 205 seconds on the task; 82 seconds more than our expected time. The participant used only one hand and swiped on the screen with his thumb, reducing the distance covered with each swipe. This accounted for 71 seconds of the additional time. We note that this time was due to the mechanics of swiping, and was not obviously related to interface differences between SBS and SWP.

Using the IMS method, P11, spent 103 seconds which was close to the expected time (16 seconds more, most of which was due to asking for a question to be repeated rather than interaction behaviour). The participant stood at the center of the projection, and held the phone just above the waistline, quickly moving it to point to targets.

P9 spent 166 seconds using the IMS method, which was 79 seconds more than our expected time. As with P11, this was not directly related to interaction behaviour: the participant spent a lot of time describing the locations of answers, accounting for about 50 seconds of the extra time, and took additional time redoing a question. As with other participants, P9 moved the focus to the circled region when looking for the school, read the detail to see that it wasn't a school, then visually scanned the context for the school location, then moved the focus to the correct location to read the answer.

The colored line on the context were working as a marker, so they were invisible on the phone screen. In IMS and SBS, participants were able to directly point to the start and end of the lines without following them, but in the SWP, both participants spent time to adjust the location of the markers at the correct place that they can read the answer. Because of the guidelines on the map, this task was completely dependent to the context, so even in IMS method, participants should use the projected picture to find the start point and end point of the lines, and then use the phone to find the answer. Figure 72-right shows that SBS and SWP were more dependent to the context than IMS, but in this task there was no big difference between the time on focus and context. In the last question of task, we asked participants to find the location of a school. All participants used the context, and when they found a name, they used their phone to check the name of school. While 5 of six participants pointed to the highlighted building, they found that there was no school, so they traced the entire of map to find the answer, and because the school was located on the bottom part of the map, they spent many time on the context.

The last task that we evaluated is "DDR3 memory" diagram (Figure 73) from the search category. In this task, some text was legible in the projection, but there were no markers or guides on the image, and all questions were based on searching for text.

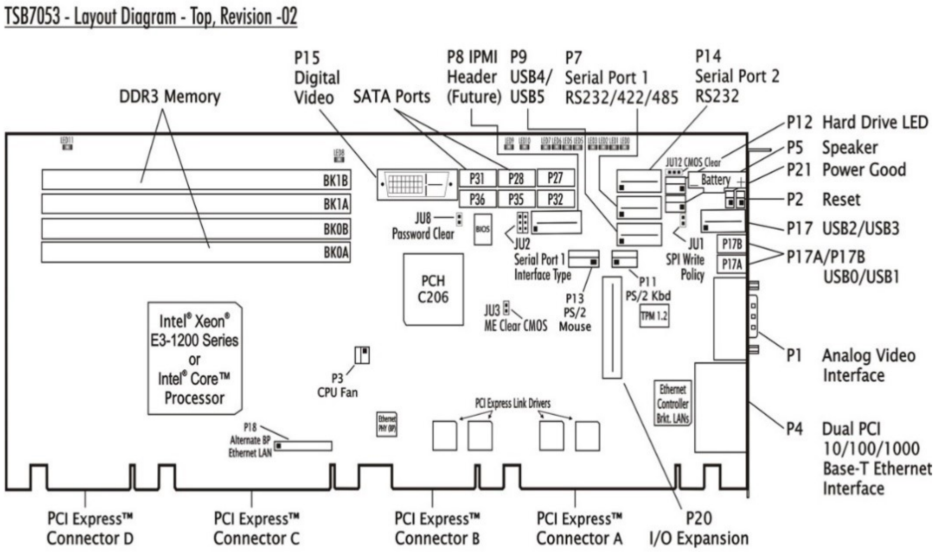


Figure 73 "DDR3 Memory" Task

The first question was “how many DDR3 memory slots exist on the board?”. The projected picture was blurry, but the large text was legible, however 5 of 6 participants prefered to use the clear picture on the focus device. In the second question we asked about the series of processor on the board. Similar to the first question, the third question (“what is P20 port?”) was legible on the context. In the next question, we asked participants to find the “analog video interface port number”. In the fifth question, which was “what is the PS/2 mouse port number?”, when the answer of question was very close to the question 4, in SBS and SWP participants found the answer faster than IMS. The last question was: “what is the digital video port number?”.

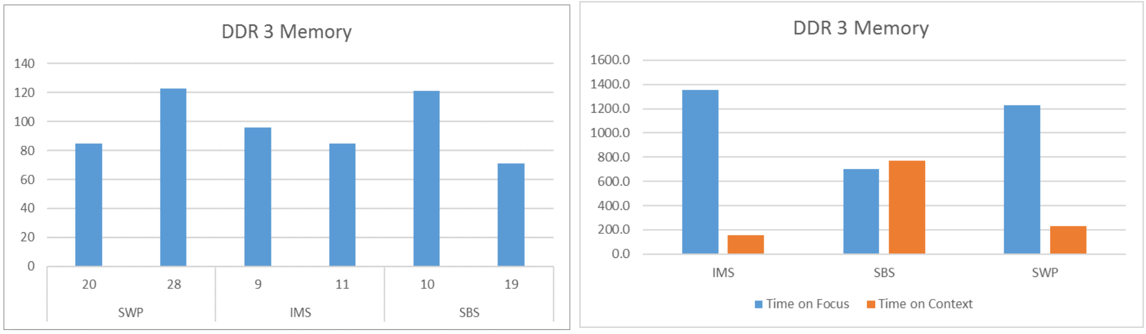


Figure 74 Time completion of tasks for selected participants in "DDR3 Memory"

Based on our expected time for SBS method, this task should be done in 76.1 seconds. P19 spent 71 seconds which was was close to the expected time (5 seconds less, was due to the answer's location of Q3-Q5 and faster searching and pointing on the diagram).

User P19	
Q1: Search-Point: 3 sec Read: 1 sec Q2: Search-Point: 4 sec Read: 1 sec Q3: User asked to repeat the question: 2 sec Search-Point: 8 sec Read: 1 sec Q4: Search-Point: 2 sec Read: 1 sec Q5: Search-Point: 9 sec Read: 1 sec Q6: Search-Point: 6 sec Read: 1 sec End: 2 sec	Q1: A+G(1)+Q1(3.9)+M(1.35)+SP(3)+R(1) =10.25 Q2: G(1)+Q2(2)+M(1.35)+SP(4)+R(1) =9.35 Q3: G(1)+Q3(1.3)+Error(2)+M(1.35) +SP (8) +R(1) =14.65 Q4: G(1)+Q4(2.8)+M(1.35)+SP(2) +R(1) =8.15 Q5: G(1)+Q5(2.9)+M(1.35)+ SP(9)+R(1) =15.25 Q6: G(1)+Q6(2.5)+M(1.35)+SP(6)+R(1)+E(2) =13.85
Time: 10.25+9.35+14.65+8.15+15.25+13.85 = 71.5	

The participant P10, spent 121 seconds to finish this task: which was 45 seconds more than the expected time (76.1 seconds). In visually scanning the context, he first found 2 slots of DDR 3, but by moving forward and counting on the context, he changed his answer to 4, which costs additional 5 seconds. P10 used only focus device to scanning the entire of map for question 2, and he spent 17 seconds (13 seconds more than the expected time, when it was visible on the context). Finding the answer of this question takes 33 seconds: which was because of the location and small text size of the Q5's answer. 10 seconds visually scanning context was not helpful, so P10 used the focus device to search the entire of map, which was 21 seconds more than our expected time.

In IMS method, P11 completed the task in 85 seconds: which was 12 seconds more than the expected time, because of repeating the question.

P9 used IMS method and he looked at the context area only one time for 1.2 second. He finished the task in 96 seconds: 23 seconds more than our expected time, which was due to search the entire of map in 13 seconds. In question 3, he did not not pay enough attention to the data on the phone because of the fast responsiveness of IMS. He moved one step back to be more far from the projected screen and have a better control on the phone screen. After that he searched again a bit slowly and found the answer, but he spent 17 seconds, which was 11 seconds more than our expected time.

P20 never looked at the context screen, and he spent 85 seconds on this task using SWP: only 7 seconds more than our expected time. All of this time was spent on the first question.

In this task, P28 spent 123 seconds to complete the task: 45 seconds more than our prediction. Much of this time was for tracing the entire of map (17 seconds for Q2). As we said before, he was very slow in swiping bu thumb. P28 had little attention in searching action. In three occasions, he did not complete the search action and he just turned when the location of Q3 answer was very close to be visible on the focus device. (34 seconds for four times searching, 24 second more than the expected time).

In IMS, both participants searched the entrie of the projection more than one time to find the answer of each question. We believe that they did not pay enough attention to the texts at the first time.

As we can see in Figure 74-right, in IMS and SWP, the amount of time that participants spent on context was very small. The collected data show that, one participants in IMS and both participants in SWP used context for less than 4 seconds in this task, which we could assume that they did not use the context and they just looked at it. When the location of answer in the last question was on top of the picture, the user spent more time than our predicted time to find the answer. When most of the previous question were on the right side and bottom of the picture, the participant most attention was on that part of the diagram.

To put it briefly, in SBS, when the overview of picture had some useful information on the context, participants spent more time on that, and they tried to use it as a guide to find the location of answers. On the other hand, in IMS method, because of the fast responsiveness to user interaction, the participants had little pay attention to the focus device and they spent more time than they required to complete a task because of the two or three times entire search. In the search type tasks, the SWP method was very similar to SBS if the context does not have enough useful data, but in the tasks with marker, the SWP required a bit more time than SBS, as we can call it "adjusting time".

In summary, we learned that if some guides, such as markers (e.g. colors, texts), and natural features (e.g. small lake) were available on the focus device, users less looking to the context, however, users are dependent to the context on tasks that included markers as a guide (e.g. added numbers, colors) which were invisible on the focus device. Moreover, we learned that in the search tasks, the IMS method is less dependent to the context, when it is fast responsive. We learned that there are other factors that might affect the performance. For example while searching to find the location of the answer takes long time, they may forgot the question. We found that the ambiguous question, or not completely attention to the goals of the question were causes for repeating the question or describing it. We learned that users abilities to use the touch screen device was different and some users are naturally working slower on swipe gestures but some of them are very fast.

5.3.4 PhoneOnly Evaluation

To evaluate how a user interaction is different between using an mF+C system and the current applications, we compared Time of the three mF+C methods with a PhoneOnly method that uses a basic photo viewer application. A stopwatch was used to record the time for the PhoneOnly method. We measured the time in the same way as previous evaluations for mF+C system methods.

Since we had only two tasks in the PhoneOnly method (one map and one board), and by default in optimal condition, we compared the PhoneOnly board tasks with an optimal board with similar type of tasks. The expected time complexity for PhoneOnly method is 47% faster than mF+C methods. We also ignore comparison between the content types

(Map vs. Board) in the PhoneOnly method since we do not have comparable tasks with similar characteristics.

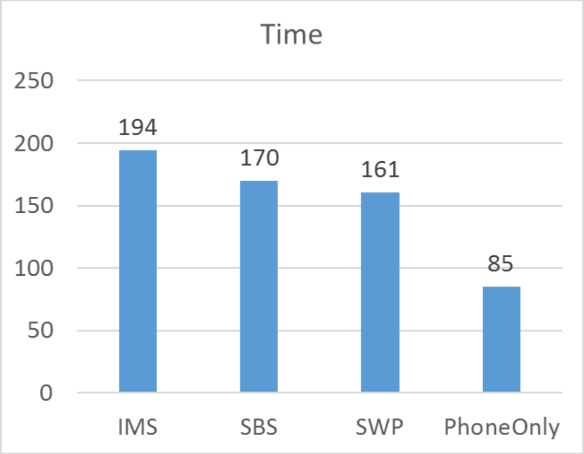


Figure 75 Average of Time for mF+C system methods and PhoneOnly

The average *expected* time (using adapted KLM) for performing board task in the PhoneOnly method is 52.15 seconds, and we selected one optimal board task with a similar type of task with expected time of 98.20 seconds that we used for IMS, SBS, and SWP. We acknowledge that this comparison is problematic since diagrams are differ between PhoneOnly and the other methods, but we report it here as a rough point of comparison. Because of the task design, the expected time on PhoneOnly task was about 47% faster than the average of expected time in mF+C method. Figure 75 show that, the SBS and SWP are about 50% slower than PhoneOnly method which is quite similar to the expected time, but PhoneOnly is faster than IMS, however by considering the 47% difference because of the task design, this amount of difference is not significant. We believe that familiarity with the method has an impact on the time of using the mF+C system. In the PhoneOnly method, the last question in the board task was finding the value of a component on the black square marker. The observation notes show that 33 participants spent 15 secs more than similar questions that had different color or shapes rather than black-square to find the answer, and three participants could not find it. In the interview, participants reported that because of the black square, which was similar to the electronic components, it was difficult to find it in an overview. As a result, when the participants were not significantly faster in completing the tasks on PhoneOnly compared to mF+C methods, so we cannot prove that the mF+C method is taking more time for task completion.

5.3.5 Post-method questionnaires evaluation

As we mentioned in the previous chapter, after completing four tasks with one interaction method, participants filled out a questionnaire with 6 to 8 questions about the method experience. In this section, we are looking at the participants' responses and finding the reason for the significant differences between the responses. We use the results from the other data collection instruments, such as sensor logs, recorded videos, and observation notes. Figure 76 on the next page shows the participants view in Likert scale for each interaction method for different questions.

According to the questionnaires, with a chi-square test, we found that most of the participants agree that information provided on the phone was accurate and properly aligned with the projected picture in IMS (χ^2 (1, N=36) = 42.06, $p<0.001$), SBS (χ^2 (1, N=36) = 76.50, $p<0.001$) and SWP (χ^2 (1, N=36) = 27.61, $p<0.001$).

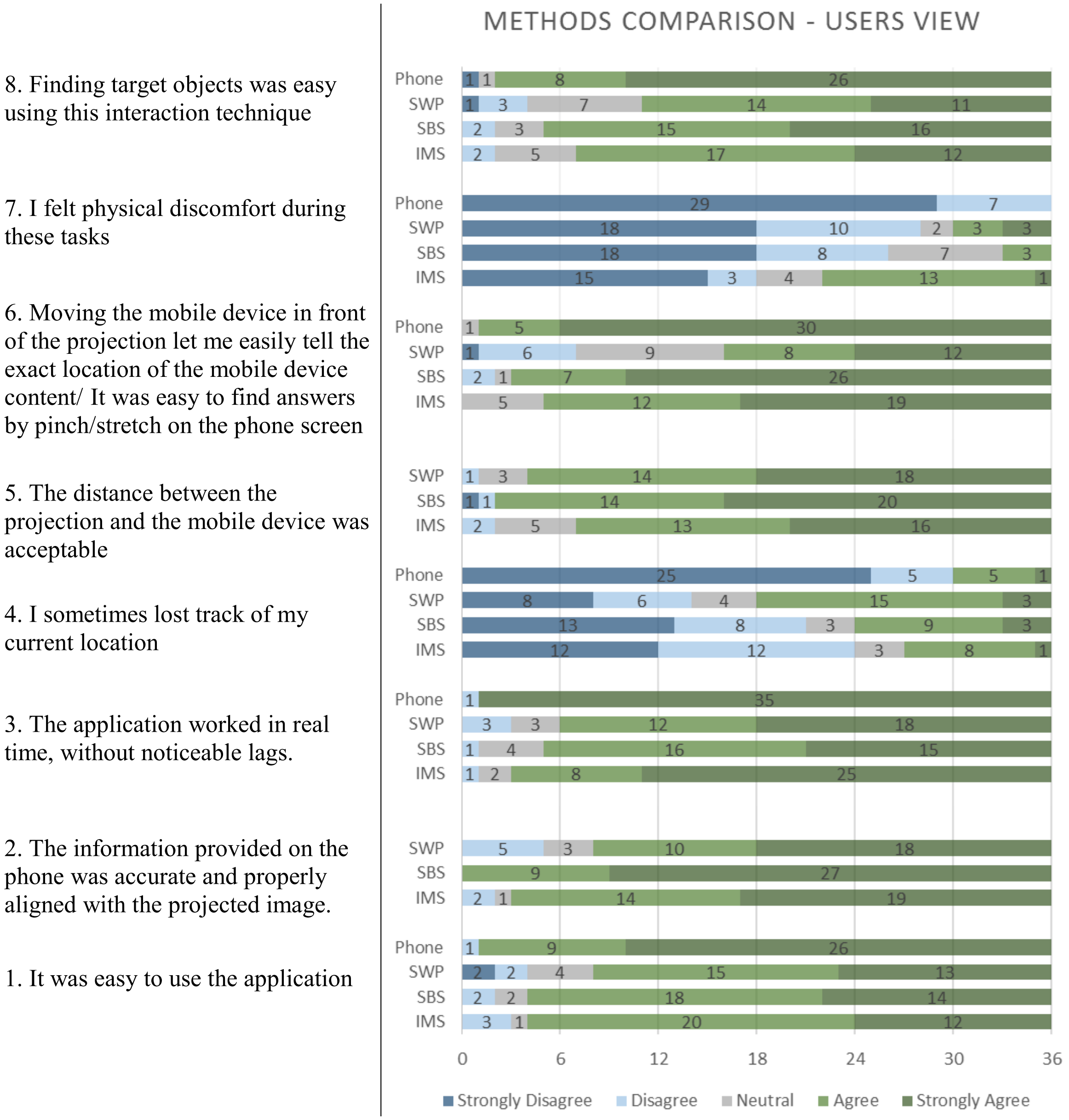
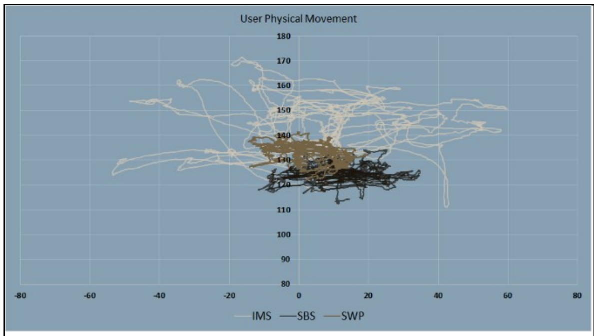


Figure 76 Post-method questionnaire responses

While none of the participants felt physical discomfort during the tasks using PhoneOnly method, 8.34% of the participants on SBS and 16.67% on SWP reported their discomfort using those methods. With a chi-square test we found that participants who used IMS method were significantly uncomfortable on this method (χ^2 (1, N=32) = 0.28, p=0.6). Samples of the collected data from sensors for six participants are represented in Table 27. The X-axis represents the left-right participants hand movement for 160 cm and Y-axis represents top-down participants' hand movement from 80 to 180 cm from the floor. The

IMS method is shown in light brown, the dark brown is for SWP, and the black line indicates SBS method. It can be clearly observed that all the participants moved more lateral in IMS than SBS and SWP. Moreover, none of the participants holds the phone higher than 135cm from the floor, which is between the waistline and the chest, in all SBS and SWP methods, except user P2 that holds the phone between 122 cm to 141 cm in SWP. However, in IMS method, all participants hold the phone higher than SBS and SWP.



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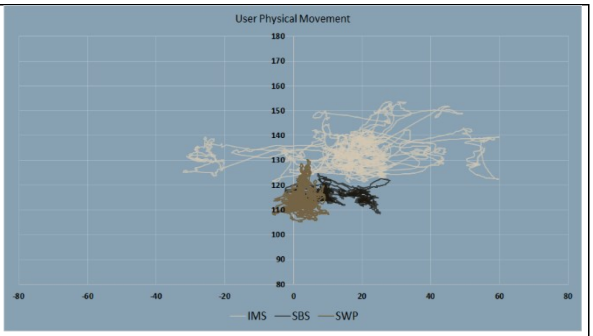

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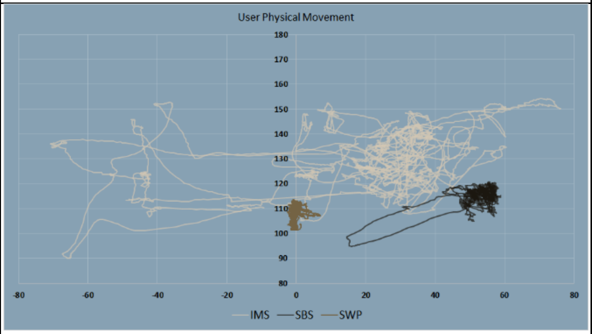

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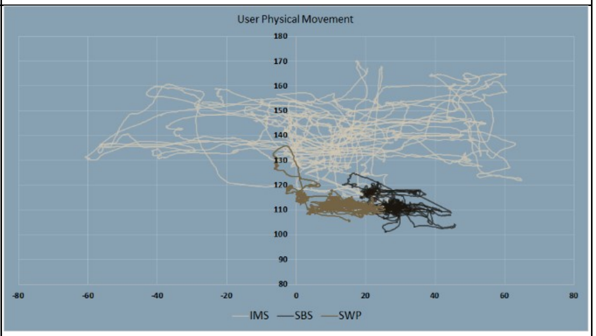

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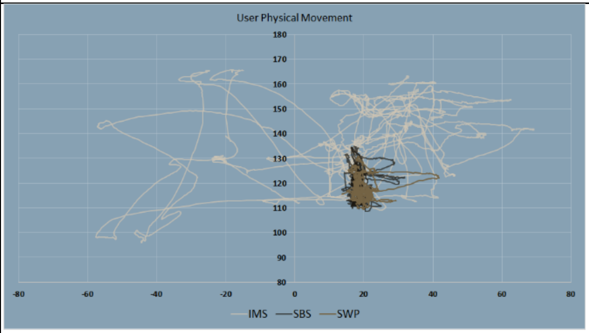

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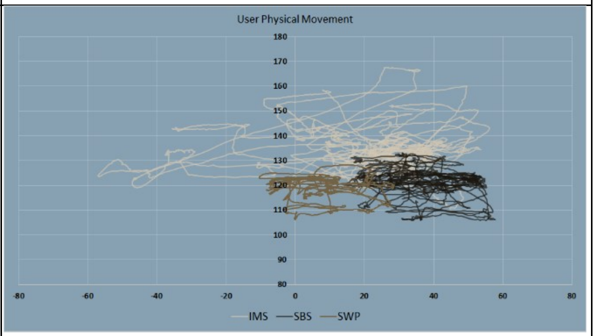

ID: 36

Table 27 Six participants hand movement visualization

The average of participants' hand movement in X (horizontally) and Y (vertically) is available on Table 28. While the average height that participants hold the phone in SBS and SWP is 118, this average for IMS is 16% more than other methods.

Method	Average of X-movement (width)	Average of Y movement (height)
IMS	120	137
SBS	31	118
SWP	27	118

Table 28 The average of hand movement for each mF+C method

Considering that all tasks are performed in all the mF+C methods, the average movement for SBS and SWP may be due to less required device movement to/from the center of the context screen while for IMS the device is moved all around the context screen.

Furthermore, referring to the recorded videos from the front camera, we observed that all participants hold the phone at an angle of 65 to 90 degrees based on the pitch axis, which is in the direction of the projected picture on the wall. Figure 77 shows that based on the collected data from the phone gyroscope sensor, participants hold their phones at an angle of about 80 to 110 degrees.

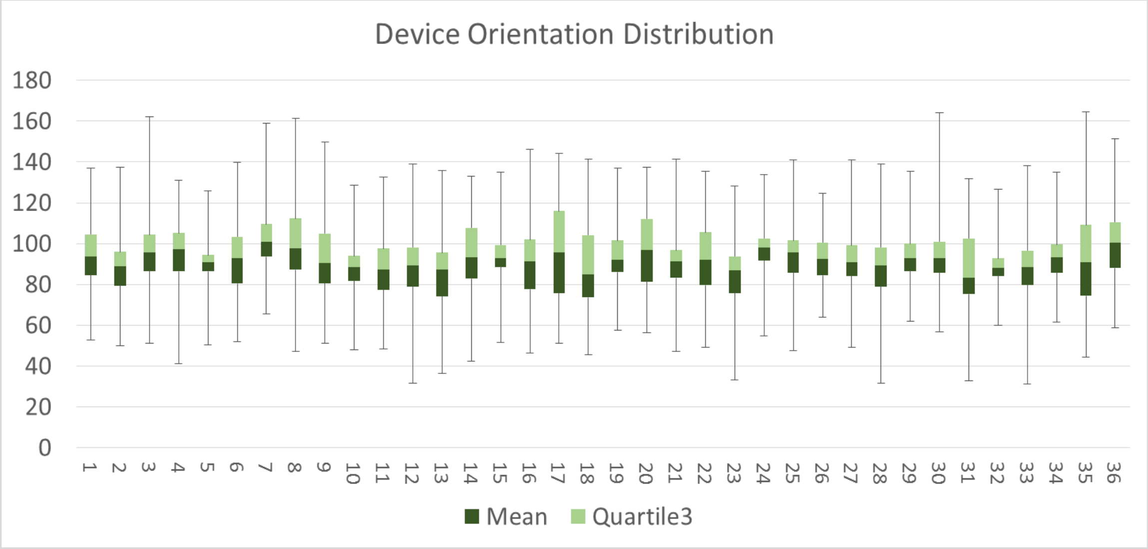

Figure 77 The distribution of device orientation on the pitch axis for all participants

We believe that the number of questions in the sequence has an impact on physical discomfort in IMS. The average time to finish the tasks in this method was 522 seconds (8 min and 48 sec) which seems too long for holding a mobile phone in line with the projected picture using a raised hand in front of the projection area. Because of this hand fatigue while using IMS method, two participants (ID 6, 26) switched their hand to hold the phone in between the tasks.

Method	Percentage of users who found method was easy	Pair	Mean	SD	t	df	p-value
SWP	55.56	IMS - SBS	.194	1.11	1.04	35	.303
IMS	86.12	IMS - SWP	.722	1.27	3.38	35	.002
SBS	91.67	IMS - Phone	.416	.87	2.86	35	.007
Phone	97.20	SBS - SWP	.916	1.50	3.66	35	.001
		SBS - Phone	.222	.95	1.39	35	.173
		SWP - Phone	1.138	1.29	5.29	35	<0.001

Table 29 The percentage of easiness for each method and stats of easiness comparison between a pair of methods

Since a bit more than half (55.56%) of the participants in SWP and 91.67% in SBS reported that using the method was easy, there was no significant difference between IMS (86.12%) and PhoneOnly (97.20%) methods, however, there was a significant difference between SWP and all other methods (see Table 29).

Method	Lost location (%)	Chi-square test
SWP	50	χ^2 (1, N=32) = 0.28, p=0.6
SBS	33.34	χ^2 (1, N=33) = 1.94, p=0.17
IMS	25	χ^2 (1, N=33) = 5.94, p=0.015
Phone	16.67	χ^2 (1, N=36) = 14.7, p<0.001

Table 30 The percentage and stat of lost location for each method from user responses

Table 30 shows that half of the participants in SWP and 33.34% of participants in SBS reported that while performing the tasks, they lost their location with respect to the projected picture, which is significant with IMS and PhoneOnly. In SWP, participants needed to match the picture on the phone with the projection by moving the projected picture and putting it in the direction of the phone location. During the trial task, participants learned how to control the picture and how the pictures are related, but it was common that participants were unclear about how the system works during the first or second task. Since participants need to switch between two screens to find the answers, they might lose the location of the viewfinder during the tasks. In summary, the participants were more confident with IMS and PhoneOnly methods as they did not lose their location significantly.

	Best - 1	Mid - 2	Worst - 3
SBS	18	15	3
IMS	17	14	4
SWP	1	7	29

Table 31 The rank of methods from participants' point of view

Table 31 shows the favorite methods sorted by participants from one to three where one is the best method. In total, 18 participants selected SBS and 17 participants chose IMS as the best method. In addition, 29 participants (80%) found that SWP was the least favored method, χ^2 $(1, N=36) = 36.17$, $p<0.001$.

In the next chapter, we will discuss what the results indicate with respect to the research questions of this thesis.

CHAPTER 6 DISCUSSION

In this chapter, we will discuss what we have learned from the mockup implementation, user study, and how the results answer the research questions. As the graph of our user study for mF+C system > Methods > Conditions > Type of contents is illustrated in Figure 78, we are discussing the highlighted sections upward from level (1) to level (4).

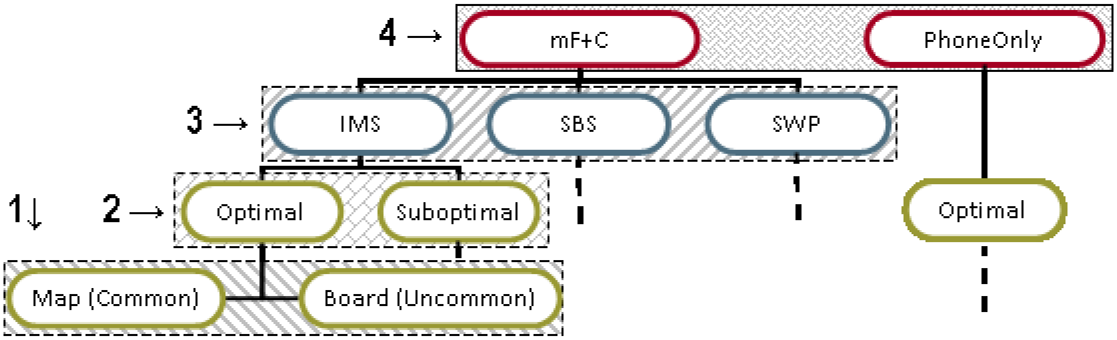

Figure 78 Structure of experiment design

6.1 Discussion and analysis

The experimental apparatus and mF+C methods are designed to evaluate how we can access the information on a large display with details everywhere. In this research, we considered three types of interaction techniques with a provided large content, using a mobile phone. We conducted a laboratory user study to find the advantages and disadvantages of each interaction method, and to evaluate how well mF+C works in situations with poor context visibility and finally, how content type familiarity affects an mF+C system.

Section 1: Content type

In the user study, the tasks were related to two types of pictures. We used maps as a type of picture known to all participants and electronic boards as a type that about half (17) of the participants felt familiar with. According to the interviews, 24 participants agreed that finding the answers on the map was easier than the board, 10 participants did not find any differences between map and board and two participants considered the board easier than the map, so, the result confirms the selection of two diagram types as representative of familiar vs. unfamiliar content type. Since urban maps are more familiar to many people than electronic diagrams we were anticipating that in the mF+C methods, finding answers of tasks on a map would be faster and more accurate than an electronic diagram because people would bring prior experience to bear when working with a map. The results show that there was a difference in completing the tasks between types of pictures. The results indicate that all participants performed tasks on Map faster than Board; however, for those participants who were familiar with the board, the spent time on the board was not significantly different from the time on the map.

Familiarity with the type of content is important when it has direct impact on how people use the context. For example, Familiar user with electronic board need less visual markers on the board and they are less dependent to use the context, however the Unfamiliar are looking for additional markers that can help them to find an object on the context, and regardless of methods, they are more dependent to the context, so an application developer should consider this factors in designing process.

In previous F+C, O+D, or off-screen location technique such as, Wedge[23], Halo[4], and Canyon[27] the user's familiarity with the content type was not considered as a factor when considering the usability of the system, however we show that familiarity with content type has impact on performance on using an mF+C system.

Section 2: Conditions

In regards to our research question, "how do details on the phone screen adequately compensate for poor context visibility due to projecting on non-planar and/or non-uniform surfaces", when the projected pictures were manipulated to represent content in different light conditions and surface materials.

In particular, participants spent more time on suboptimal than optimal conditions. However, there was no significant difference in time between optimal and suboptimal for the IMS and SBS methods. From the videos and observation notes, we observed that in the optimal condition, participants tried to guess the answer or find the answer location by looking at the projection area. However, in suboptimal condition, the projected picture does not have enough details that user can find the answer just by looking at it; so they spent more time to find the answer or the area of the answer than in optimal conditions. In tasks that finding the answer of question was dependent to the marker on the context, while the markers were not visible on the phone screen, participants should use the context. In optimal tasks, by pointing to the markers and matching the surrounded shapes on the context with the phone screen, finding answer was easier than suboptimal condition when the context was fuzzy and participants required more time on context to find the correct answer.

The result shows we can access to the information on a large display with distributed details and without concern for the environmental effects. SWP and SBS appear less able to compensate for loss of projection visibility. An analysis of attention on focus vs. context screens suggests that the SWP and SBS methods require more frequent viewing of the context image, particularly in suboptimal display conditions.

When in Canyon[27], both overview and detail were in the same plane, the environmental effects such as light or unclear surfaces have an impact on details of the information. However, in the mF+C system, with a high-resolution focus device in hand and projected content on a surface, users can have access to the detail of information regardless of the environmental effects.

Section 3: mF+C methods

According to the post-study interviews, the number of participants who preferred to use SBS or IMS was about equal, while 29 out of 36 participants reported that the SWP was their last choice. By analyzing the post-methods questionnaires responses and interviews, we identified that feeling the physical discomfort during the tasks was the primary concern about IMS. As we mentioned in chapter 5, the average of time to completing the tasks in IMS method was more than 8 minutes, and during this time participant held up the phone in front of the large picture, so this exhaustion likely affected the choice of favorite method. According to the post-methods questionnaires results, SBS was ranked the most favored method as to whether the information provided on the phone was accurate and properly aligned with the projected content. From the interviews, we observed the viewfinder on the projection area was a second motivation of participants to prefer SBS to IMS. In addition, two participants reported that *"if IMS had a viewfinder"*, that method was absolutely their first choice. Furthermore, from the same questionnaire, the participants reported that they lost track on the IMS less than SBS and SWP. After analyzing the interviews, we recognized that the participants who preferred the IMS method believed that moving around the projected content was easier than swiping on the screen in SBS method. Participants 1 and 26 stated that *"because the application operates in all directions"*, they got a good sense of working without noticeable lags. Discussing technically, SBS and SWP do not require phone location tracking; however, the IMS needs a tracking system to know how to calibrate the phone content with projected picture, therefore, implementing the IMS method is technically more challenging than SBS and SWP.

In SWP implementation, finding the answer of question is dependent to the location of the previous question, because in SWP method, while users moving the projected picture, they lose the overview of the context, so if the answer of the question will be outside of the projection, they could not find it at a glance, and they have to relocate the projection to the center and in this time, they might be forgot the question. In SWP the projected image was synchronized with the phone in the center of the projectable area, which means moving the phone does not affect the image position. If the projected image position was related to the phone position/orientation, users would have always known where the phone image was relative to the projected image, which might have helped them to have a better performance on tasks. However, before starting tasks and during the training tasks we had informed participants that the phone had been calibrated with the projected image in the initial position. We consider this problem as one of the causes that SWP was ranked by the users as the least favored method.

As we described in methods implementation section, for SBS and SWP, we first proposed a mode for touching the edge of the screen to control the movement of the viewfinder or projected image, however in the final implementation we used normal swipe gesture. In our application, by swiping nine times on the screen the user can reach to the left edge of the picture from the right edge. For moving from top to bottom, they need four times swipe from the edge top to the bottom edge. If a picture is extra-large or the task needs more jumping from left to right and top to bottom and vice versa, user may feel discomfort in using this method, while this does not happen in the first proposed method. Assessing the usability of this method and comparing it with the normal swipe gesture can be an interesting topic for future research.

SBS has a pointer, and it is easy to put the pointer on the markers and find the answer. But there are some problems. First, the pointer is a part of the projection, so if the projection is affected by environmental effects, the pointer is also affected. As a temporary solution we can adjust some of the properties of a pointer to be more visible, for example by changing the contrast or color of the pointer when it is projected on a dark surface. In SBS user have access to the overview of the projection anytime, but same as SWP, the SBS is also dependent to the context.

We found that in IMS, the number of switches between the two screens and the time on the projection area were both less than SBS and SWP. This result shows that the participants could focus more on finding answers rather than on how the system is working, or if the pointer is in the right place, or if has the projected picture has moved to the right be aligned with the phone position, so we concluded that IMS is less dependent to Context visibility.

In IMS, when there is no pointer, or user do not need to control the projected image, so user is less dependent to the projection. Here is the point that why immersion is important in IMS method. When SBS and SWP are dependent to the context, in IMS user just need and overview of the picture behind of the phone. According to the Bernstein [15], the perception can be divide into two process. The first is transform low-level information to high-level information, for example, extracts shapes for object recognition, the second, is processing which is connected to the person's concept and expectation or knowledge and attention that influence perception. So, when they are aware of their surroundings, they are using their senses to explore and understand what is the projected, how the method works, processing questions and making a decision to answer the question, but they do not need to staring at the context. According to the Goldstein [20], perception is mostly effortless, because this processing, happens outside conscious awareness.

As a result, in IMS, there was no significant difference in time between optimal and suboptimal conditions and by considering participants' answers, comments, and suggestions, we can state that, in the suboptimal condition, the IMS method has more advantages than SBS and SWP methods.

Section 4: mF+C methods vs. PhoneOnly

There are few types of interaction on a smartphone while using simple applications such as photo viewer and document management. Single/multiple taps, swiping, pinch, stretch, and the amount of pressure on the screen are common methods of interaction. We evaluated how people find the answers to questions in a large document using a mobile phone with a simple photo viewer application, in comparison with methods developed for mF+C. The nature of SBS is same as PhoneOnly when the data on the phone screen is the same as the data on the projection area viewfinder and because the SBS is not related to the device position and orientation. The SBS/SWP method is only showing a portion of the image, while PhoneOnly shows the entire image. If one zooms out on SBS/SWP, using the controls and does not pay much attention to the projection then it is truly like PhoneOnly (the only difference is how zoom + pan works). If one does not zoom out, then these methods are not the same as PhoneOnly, and they need to context switch to navigate. In SBS and SWP, the context can help users to find the answers by following the additional visual markers (if they exist) which are not available on the details. In addition, in all IMS, SBS and SWP methods the picture on context and focus could be related to each other while they are not the same. Based on our collected data, we could not identify a significant difference between PhoneOnly and SBS, which can be an interesting experiment for future work.

Considering the time, the PhoneOnly method was 8% faster than IMS and SBS with a significant difference with SWP. In PhoneOnly, participants only used the phone screen, however in the mF+C methods the participant's attention was divided between Focus and Context. When users have difficulty to find target objects while switching between multi screens, visual markers can help them to reduce this problem[24]. The results of our study also show that the participants spent more time on context in the suboptimal condition compared to the optimal condition. In addition, the cost of switching between displays is calculated in [44] based on *attention shifts, visual/input space mismatch and distraction* factors. The results also indicate that the task completion time and the number of gaze shifts are directly related to each other. As a result, because in PhoneOnly, the participant's attention is on a single small screen instead of two, and there were no gaze shifts, they performed tasks faster than mF+C methods.

From the demographic questionnaire, we observed that all participants were familiar with at least one of the zooming techniques, such as double tap, pinch or stretch. In addition, all participants had experience using at least one of the currently popular mobile map applications; therefore, they did not need to become familiar with a new technique. The User's background knowledge of how to use the system is another reason for supporting the better time in the PhoneOnly method. As we described in results section, 33 out of 36 participants had spent 15 seconds more time to find a black square marker on board compared to the other markers in different shape or color, when it was difficult to find it in an overview. We agree that because of the phone screen size (~5" in our case), and increasing the density of elements on the content, finding objects in an overview on the phone takes a longer time (or maybe impossible) than an overview on the projected picture (92" in our user study). We believe that a PhoneOnly method might be useful for documents and pictures with low-density content when items are identifiable in an overview; however, the overview is missing in PhoneOnly when users are looking at details. We believe that an mF+C system is useful for large and complex maps, such as aircraft technical diagrams, technical guides, and schematics, or Google map, but based on our results, we could not prove this theory at this time.

According to [3], because of the large available drawing area, there was "lots of space" to work in original F+C system for people who were working on large documents from hardware designs to graphic contents such as posters, sketches and web. However, people who were working on text documents were not interested on F+C. We consider that extra-large documents with super high amount of details (e.g. blueprints of an airplane engine) could not be useful on a small display of a phone or a tablet, while users need to see them on a large screen. In this case, an mF+C can be a solution. An mF+C with a large overview provider and high-resolution details in hand is portable and available everywhere. While in PhoneOnly the user attention is just on a single point of focus, in mF+C the overview of data is always available and can also be shared with other users. This lead us to open a research question for future study, "What type of data need an mF+C system?"

Whereas both the mF+C system and the PhoneOnly method are portable but the mF+C system,would let the users to have different linked views of information at the same time. As we described in related work, Goncalves et al. [21] analyzed the effect of the overview scale on mobile O+D interfaces, using map application in Classic, Split-Screen, and Resizable interfaces. We believe that the accessible information in an overview is directly related to many factors such as the content density, number, and size of the visual markers and size of the device screen. However, in the mF+C system, when the large (e.g. 92-inch) picture is projected for an overview, we can use the whole area of the phone's screen only for information details. In addition, the portable focus device in hand let users stand away from the context, so they can have a better overview of the projected picture,

Currently, the IMS method poses some technical hurdles because of the need for device tracking. There are two options available; first, using the external sensors such as Polhemus, or Vicon cameras, which are difficult to use in a real situation. The second choice is using a self-tracking device, such as Google Tango, which is still under development. Today, Tango devices are not available in the market (only researchers can order a developer kit), and the system is not stable yet, but we can predict that the commercial devices will be available soon. Until that day, by forgoing some of the features (e.g. movement in any direction, interactive zoom, user's head relation), we can use built-in sensors (e.g. gyroscope, accelerometers) which are available on the most of the phones for interactions.

While in all tasks we used static images, we believe that mF+C is also good for animated images. Dynamic graphs and visualized data could be applied to the mF+C system. IMS is fast response technique, so we can track a live motion from side to side of the projection if the speed of movement does not make the fuzzy picture on the phone.

6.2 Limitations

There were some limitations for this project.

Method design: In SBS we had two buttons to control the level of zoom, but during zooming in/out the rectangular pointer size on projection was not changing, which was one of the SBS method design mistakes. In SBS and SWP there was no notification feature to notify the user about the zoom level of the picture on the phone whether it is in the initial zoom or in any other zoom level. As we discussed before, in SWP the projection image and the phone were coupled in the center of the projectable area, and the projected image position was fixed regardless of any changes in the phone position/orientation, which was because of the fixed location of the projector. Since the projector was not attached to the phone, moving the phone was not causing the projector to move, therefore the projectable area was fixed. Moving the projection image according to the phone movement, would lead to losing the overview of the picture, so we decide to inform participants that they should stand in the center of projectable area.

Task design: While 12 different pictures helped us to prepare different types of questions, but because the tasks were not counterbalanced according to PhoneOnly/mF+C methods and Optimal/Suboptimal, we could not use all tasks for all time comparison, so we made a group of similar tasks with the same expected time for evaluation and comparing the results of each group.

Training tasks: We designed three training tasks and asked participants to work on them to get more familiar with the system and methods. The time for doing training tasks was 2-3 minutes. Since the training tasks design was not including an enough amount of challenges compared to the main tasks, some of the participants had difficulties during doing the first or second main task, specifically in SWP method that they did not understand how the method was working.

Condition design: We manipulated the pictures to simulate different projection optimality, however if have used the non-planar or noisy surfaces instead of this simulation, we could have a better real comparison between two same optimal pictures, that one of them was projected on a clear surface and the other same picture was projected on uneven surface.

Tracking system: The Polhemus tracking system-supporting range was about two meters from the Source, but because it is using the electromagnetic field technology, any metal objects on the lab make distortion and has a negative effect on the data. In our lab, because of the building structure, furniture and large electronic devices (e.g. tabletops, 4 x 60” LCD screen on the wall, ceiling lights), the sensors were not working fine. A Polhemus system providing position and orientation data for each sensor, but unfortunately in our lab, the orientation data was completely strange and unusable. We could cover the walls and floor with a wooden board to stop building's distortion, but we could not find any large and empty space without furniture in our level of the building that we can use it for a month. In addition, we had another user study running at the same time in the lab, so we could not move shared hardware and stuff such as video cameras and tripods every days or hour. To solve the orientation problem, we used the additional phone, which was attached to the back of a headband, and we collected the phone's gyroscope data for tracking the user's head orientation. During the study, we never observed any complaint from participants about the phone on the back of the head.

The Polhemus hub, which sensors are connected to it, could transfer data to PC via a USB cable or wirelessly on 2.4 GHz RF. At first, we tried to use wireless mode, but because of the noticeable lags, we switched to the wire mode. However, because of the USB cable length support, which was limited to 2 meters, the experiment working space was decreased.

Head Tracking: We found that using mobile phone on the back of the head was not a useful method because we could not collect valid required data from the sensors, which was a result of the phone instability on the head. Another issue raised for the female participants who had tied their hair on the back or top of their head, which made it difficult for them to keep the headband and the phone in the right place at the back of their head.

6.3 Application

In this project, we were inspired by the work of aircraft mechanics, technicians, engineers and others who work with large technical documents that need to be accessed in suboptimal conditions while performing physical and/or mobile work. As we learned the mF+C system could cover the environmental effects, and generally, it works in an acceptable time, we found that an mF+C system, particularly an IMS approach, is useful when the projected screen operates as an overview of data and a mobile phone with a high-resolution screen would show the information details. Train the users to use the system and user familiarities with content type are other notable factors in using an mF+C method.

mF+C system could be useful in projection mapping. For example, while inside of a device is not visible, by projecting an overview of the device on the body, the person can see the details of the device on the phone screen. It is also useful for large 3D objects. For example, to find how two parts of a car are connected by pipe, when the overview is projected on the hood and the particular parts are highlighted, user can trace the highlighted pipe.

6.4 Future work

In the theory of the immersive mF+C system, we have identified some features that are not finalized or fully implemented yet, and these can be considered in future work. In the IMS method, a picture on the phone screen was related to the device position and orientation, which works well, but in the real world, a picture that a person observes through a lens is related to both lens position and orientation, and the user's head position and orientation. To achieve this level of accuracy we have to add a *parallax* feature. We are working on it, and most of the implementation is already completed using two Polhemus sensors, but more testing and calibration is required before building a prototype that works well.

Another improvement on the mF+C mockup used in the study would be using a portable projector instead of the stationary one. We can evaluate how a pocket size or a Pico projector on the phone or on the user's head, shoulders or waist is more or less appropriate for mF+C. Shared displays can play a role in creating team working concept[42], so, in field studies, we can assess how multiple user configurations in mF+C system might be useful and where "availability everywhere" F+C has real value. As Bishop et al. [6] reported that users do not have much privacy on large projected displays, we can evaluate mF+C from a privacy perspective, in which a big picture is projected but details are only available on the device which is in the user's hand.

CHAPTER 7 CONCLUSION

In this thesis, by using a mobile phone and a video projector we designed a system called "Mobile Focus + Context (mF+C)". In this system, a mobile phone provides details (or another view) related to a contextual view presented on a large screen. To implement an mF+C system, first we need a projected picture on a surface. Due to environmental conditions, pictures may not be clear, text may be not legible, shapes may be unrecognizable, or colors may not be distinguishable, so the user has a suboptimal presentation of the large image. However, the user can use a phone in front of the projected picture and see details on the mobile phone. To have an mF+C system, we need a mobile phone with self-tracking system and an embedded projector on the back of it. Due to technical limitations, a system was not available at the time of this study, so we made a limited version of this system, with on the market devices, to assess what is currently possible. We also developed an experimental apparatus that approximates how an mF+C system would work from the user's perspective.

We implemented three interaction methods using the apparatus, and conducted a user study to evaluate how the mF+C system would be useful, what are the advantages and disadvantage of the interaction methods and how a focus device can sufficiently overcome the effects of the environmental conditions on content. We recruited 36 participants to perform 14 tasks with two different types of pictures (maps and electronic circuit boards). The experimental factors were the interaction methods used, and the optimality (overall visibility) of the projected context image.

We learned that an mF+C system could provide information with details on a large display in any location without concerning about the effects of the environmental conditions. In addition, we found that in the mF+C system, the familiarity with the type of the content has an impact on the performance of using the methods.

We found because of using two separated screens in the mF+C system, the user requires time to switch between screens. However, the user needs less time to switch between the screens when using IMS compared to SBS and SWP. Users also spend more time on the mobile device rather than projected picture using the IMS method, which helps them to focus more on the high-resolution focus view. Because of less time spent on Context in

IMS compared with SBS and SWP, we found that IMS needs less context visibility, which is helpful in suboptimal conditions.

Finally, we believe that an mF+C system is useful for those who need a large overview of data with high-resolution details in any location.

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APPENDIX A – INFORMED CONSENT

Using a smartphone to interact with projected content

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We invite you to take part in a research study being conducted by Majid Nasirinejad at Dalhousie University. Your participation in this study is voluntary and you may withdraw from the study at any time. Your academic (or employment) performance evaluation will not be affected by whether or not you participate. To be eligible to participate in the study, you must be a Dalhousie University student, staff or faculty currently, and have experience using touch screen smartphones. There are very low risks associated with this study. There is a low risk that some users may become frustrated or embarrassed if they experience some difficulty performing the tasks during the study but the researcher will always be available during the study to answer any questions. The study is described below. This description tells you about the risks, inconvenience, or discomfort which you might experience. Participating in the study might not benefit you, but we might learn things that will benefit others. You should discuss any questions you have about this study with Majid Nasirinejad. This study has been funded by the Natural Sciences and Engineering Research Council of Canada.

The purpose of the study is to help us to assess a number of different techniques for linking smartphone screens with content projected onto nearby walls. You will be asked to participate in an hour and a half study where you will perform a set of tasks using a smartphone. You will be asked to "think aloud" while completing the tasks and this will be video recorded. Note that this video is for analysis only; it will not be used when presenting results at conferences or elsewhere.

You will be compensated $20 for participating in the study; you can withdraw from the study at any time without consequence. A researcher is always present during the study to answer any questions you may have or address any problems that you may experience with the tasks.

At the beginning of the study, you will meet with an investigator (at the Mona Campbell building). You will be asked to give consent to do the study and to fill in a background questionnaire detailing your experience on using touch screen mobile devices. You will be given a general description of the type of tasks we want you to do with the application during the study. After doing a set of tasks, you will fill in a questionnaire asking you about your experiences with the application. You will complete fourteen tasks in four conditions this way. At the end of the study, you will answer post-experiment interview questions that will ask you to reflect on interface configurations that are presented to you during the tasks and on your general experience with the application.

All personal and identifying data will be kept confidential. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance to University policy for 5 years post publication. Anonymity of textual data will be preserved by using pseudonyms. All data collected in the video, questionnaires and interviews will use pseudonyms (e.g., an ID number) to ensure your confidentiality.

In the event that you have any difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Catherine Connors, Director, Office of Research Ethics Administration at Dalhousie University's Office of Human Research Ethics for assistance: phone: (902) 494-1462, email: Catherine.connors@dal.ca.

> "*I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that being video taped is necessary to participate in the study. I hereby consent to take part in the study. However, I understand that my participation is voluntary and that I am free to withdraw from the study at any time.*"

Participant	**Researcher**
Name: ________________________________	Name: ___________________
Signature: _____________________________	Signature: ________________
Date: ________________________________	***Date:*** ___________________

Please select **one** of the options below:

☐ "*I agree to let you directly quote any comments or statements made in any written reports without viewing the quotes prior to their use and I understand that the anonymity of textual data will be preserved by using pseudonyms.*"

Participant	**Researcher**
Name: ________________________________	Name: ___________________
Signature: _____________________________	Signature: ________________
Date: ________________________________	***Date:*** ___________________

Or

☐ "*I want to read direct quotes prior to their use in reports and I understand that the anonymity of textual data will be preserved by using pseudonyms.*"
[if this option is chosen, please include a contact email address:
______________________________]

Participant	**Researcher**
Name: ________________________________	Name: ___________________
Signature: _____________________________	Signature: ________________
Date: ________________________________	***Date:*** ___________________

If you are interested in seeing the results of this study, please check below and provide your email address. We will contact you with publication details that describe the results.

☐ "*I would like to be notified by email when results are available via a publication.*"
[if this option is chosen, please include a contact email address:
______________________________]

APPENDIX B - BACKGROUND QUESTIONNAIRE

PART I - PLEASE FILL IN THE FOLLOWING INFORMATION:

1. **Date of Birth:** ----/----/---- format: mm/dd/yyyy
2. **Gender:** ☐ Male ☐ Female
3. **Faculty/unit at Dalhousie:** ________ *If a student:*
   ☐ ____ Year Undergraduate ☐ Master ☐ PhD ☐ Other _____
4. **What brand/operating system of smartphone do you use?**
   ☐ iPhone ☐ Android ☐ Blackberry ☐ Windows Phone ☐ Other:
5. **How much time do you spend using smartphone applications every day**?
   ☐ Below 2 hrs ☐ 2-4 hrs ☐ more than 4 hrs
6. **Do you ever use your personal phone in a specific task related to your job?** (e.g. take a picture, calculation, record data, use sensors like GPS)
   ☐ Yes ☐ No ☐ I don't prefer to but I'll use it if needed
7. **Do you use any application that works with your device's sensors?** (GPS, Compass, gyro)
   ☐ Yes ☐ No ☐ I don't know what those are
   If yes, please specify the sensors that you are using:
   ☐ Proximity ☐ Magnetic field ☐ Gyroscope ☐ Accelerometer ☐ Fingerprint
   ☐ GPS ☐ Compass ☐ Pressure ☐ NFC ☐ Light Others: ___
8. **Did you ever used any remote control applications on your phone?**
   ☐ Yes ☐ No
   ☐ TV Remote ☐ Game console remote ☐ Drone Remote
   ☐ Presentation software remote ☐ Music Remote ☐ Robot Remote
9. **Do you use any map application on your phone?** ☐ Yes ☐No
   ☐ Google Map ☐ AppleMap ☐ MapMyFitness
   ☐ Bus/Train Map ☐ Offline Map (GPS Navigation) Others: ___
10. **Are you familiar with zoom in/out techniques on applications?** (pinch, double tap, etc)
    ☐ Yes ☐NO

APPENDIX C - POST-METHOD QUESTIONNAIRE | IMMERSIVE

Please respond to the following statements using the given scale (circle response):

1	*2*	*3*	*4*	*5*
Strongly Disagree	*Somewhat Disagree*	*Neutral*	*Somewhat Agree*	*Strongly Agree*

1.	It was easy to use the application	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
2.	The information provided on the phone was accurate and properly aligned with the projected image.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
3.	The application worked in real time, without noticeable lags.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
4.	I sometimes lost track of my current location	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
5.	The distance between the projection and the mobile device was acceptable	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
6.	Moving the mobile device in front of the projection, let me easily tell the exact location of the mobile device content.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
7.	I felt physical discomfort during these tasks	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
8.	Finding target objects was easy using this interaction technique	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree

1. How the mobile screen size was large enough to see the details?
   ○ Very small ○ Small ○ Neutral ○ Large ○ Very Large

2. How the projected content was large enough to focus on?
   ○ Very small ○ Small ○ Neutral ○ Large ○ Very Large

APPENDIX C - POST-METHOD QUESTIONNAIRE | SIDE-BY-SIDE

Please respond to the following statements using the given scale (circle response):

1 *Strongly Disagree*	*2* *Somewhat Disagree*	*3* *Neutral*	*4* *Somewhat Agree*	*5* *Strongly Agree*

1.	It was easy to use the application	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
2.	The provided information by application was accurate and exactly related to the context.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
3.	The application works in real time.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
4.	I sometimes lost track of my current location	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
5.	The distance between context and mobile device was acceptable for interaction	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
6.	The marker allowed me to easily tell the exact location of the mobile device content.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
7.	I felt physical discomfort during these tasks	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
8.	Finding objects was easy using this interaction technique	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree

APPENDIX C - POST-METHOD QUESTIONNAIRE | SWIPE

Please respond to the following statements using the given scale (circle response):

1	*2*	*3*	*4*	*5*
Strongly Disagree	*Somewhat Disagree*	*Neutral*	*Somewhat Agree*	*Strongly Agree*

1.	It was easy to use the application	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
2.	The information provided on the phone was accurate and properly aligned with the projected image.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
3.	The application worked in real time, without noticeable lags.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
4.	I sometimes lost track of my current location	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
5.	The distance between the projection and the mobile device was acceptable	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
6.	Swiping the mobile device in front of the projection, let me easily tell the exact location of the mobile device content.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
7.	I felt physical discomfort during these tasks	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
8.	Finding target objects was easy using this interaction technique	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree

APPENDIX C - POST-METHOD QUESTIONNAIRE | PHONEONLY

Please respond to the following statements using the given scale (circle response):

1	*2*	*3*	*4*	*5*
Strongly Disagree	*Somewhat Disagree*	*Neutral*	*Somewhat Agree*	*Strongly Agree*

1.	It was easy to use the PhoneOnly application	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
2.	The application worked in real time, without noticeable lags.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
3.	I sometimes lost track of my current location	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
4.	It was easy to find answers by pinch/stretch on the phone screen	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
5.	I felt physical discomfort during these tasks	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
6.	Finding target objects was easy using this interaction technique	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree

APPENDIX D - POST-EXPERIMENT INTERVIEW

1. Overall, what was your experience interacting with linked projected content and mobile phone detail?
2. Did you find any difference between map and board?
3. How was the distance between you and projection?
4. Which method was your favorite? Which one did you like better?
5. Do you have any suggestions to help make any of these methods more useful?
6. Do you believe the techniques could be useful in your own work? If so, how? If not, why not?

APPENDIX E - PARTICIPANT PAYMENT RECEIPT

My signature below confirms that I received a sum of $20 (CDN) from Majid Nasirinejad as an honorarium payment for participating in the "Using a smartphone to interact with projected content" research project.

Name (please print): ________________________________

Signature: ________________________________

Date: ________________________________

APPENDIX F - RESEARCH ETHICS BOARD LETTER OF APPROVAL

Social Sciences & Humanities Research Ethics Board
Letter of Approval

March 02, 2015

Mr Majid Nasirinejad
Computer Science\Computer Science

Dear Majid,

REB #: 2015-3490
Project Title: Using Smartphone to Interact With Projected Content

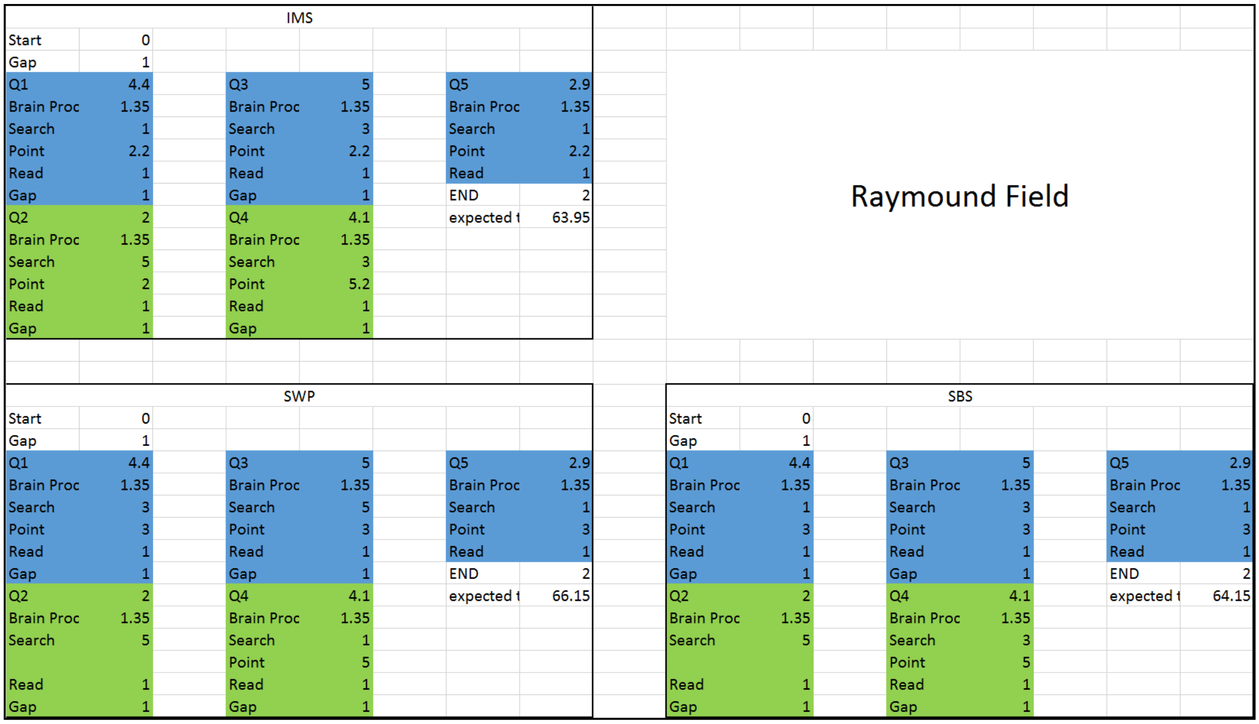
Effective Date: March 02, 2015
Expiry Date: March 02, 2016

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above.
This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Valerie Trifts, Chair

APPENDIX G – KLM FOR EACH INTERACTION AND TASK



Raymound Field

IMS

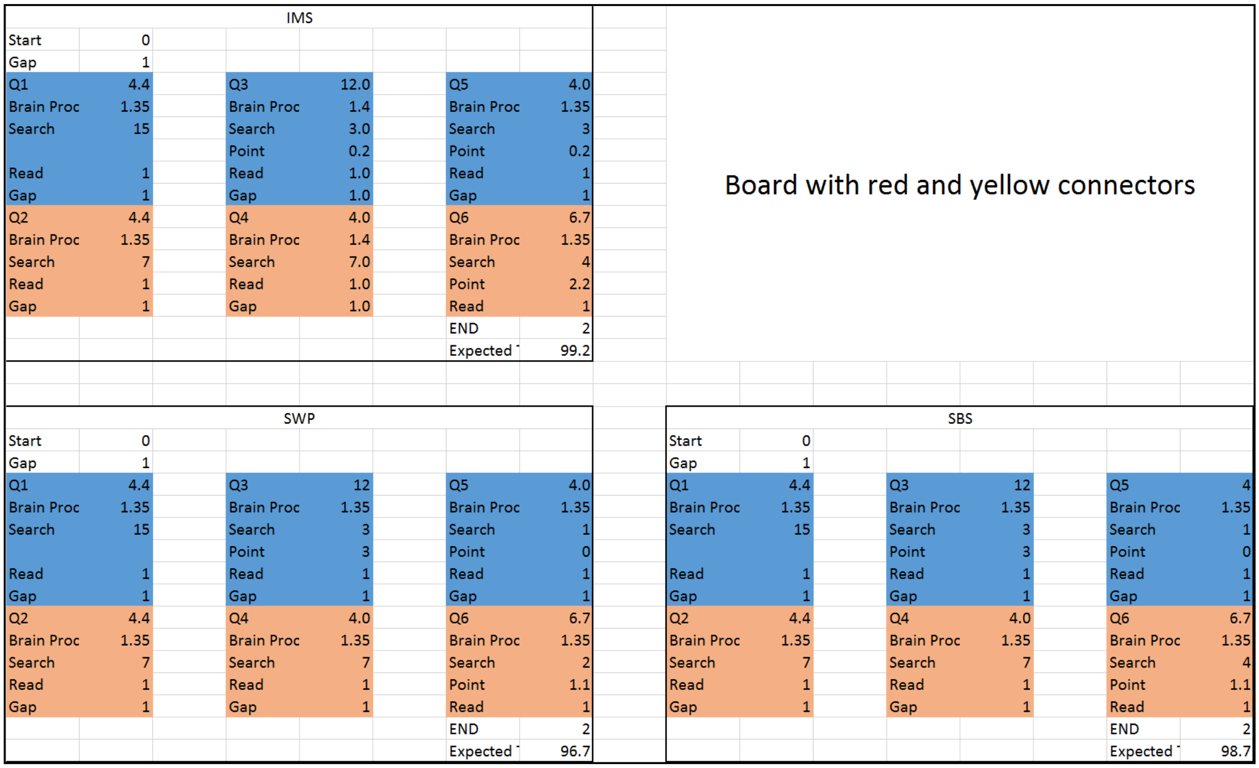
Start	0				
Gap	1				
Q1	4.4	Q3	5	Q5	2.9
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	3	Search	1
Point	2.2	Point	2.2	Point	2.2
Read	1	Read	1	Read	1
Gap	1	Gap	1	END	2
Q2	2	Q4	4.1	expected t	63.95
Brain Proc	1.35	Brain Proc	1.35		
Search	5	Search	3		
Point	2	Point	5.2		
Read	1	Read	1		
Gap	1	Gap	1		

SWP

Start	0				
Gap	1				
Q1	4.4	Q3	5	Q5	2.9
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	3	Search	5	Search	1
Point	3	Point	3	Point	3
Read	1	Read	1	Read	1
Gap	1	Gap	1	END	2
Q2	2	Q4	4.1	expected t	66.15
Brain Proc	1.35	Brain Proc	1.35		
Search	5	Search	1		
		Point	5		
Read	1	Read	1		
Gap	1	Gap	1		

SBS

Start	0				
Gap	1				
Q1	4.4	Q3	5	Q5	2.9
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	3	Search	1
Point	3	Point	3	Point	3
Read	1	Read	1	Read	1
Gap	1	Gap	1	END	2
Q2	2	Q4	4.1	expected t	64.15
Brain Proc	1.35	Brain Proc	1.35		
Search	5	Search	3		
		Point	5		
Read	1	Read	1		
Gap	1	Gap	1		



Board with red and yellow connectors

IMS

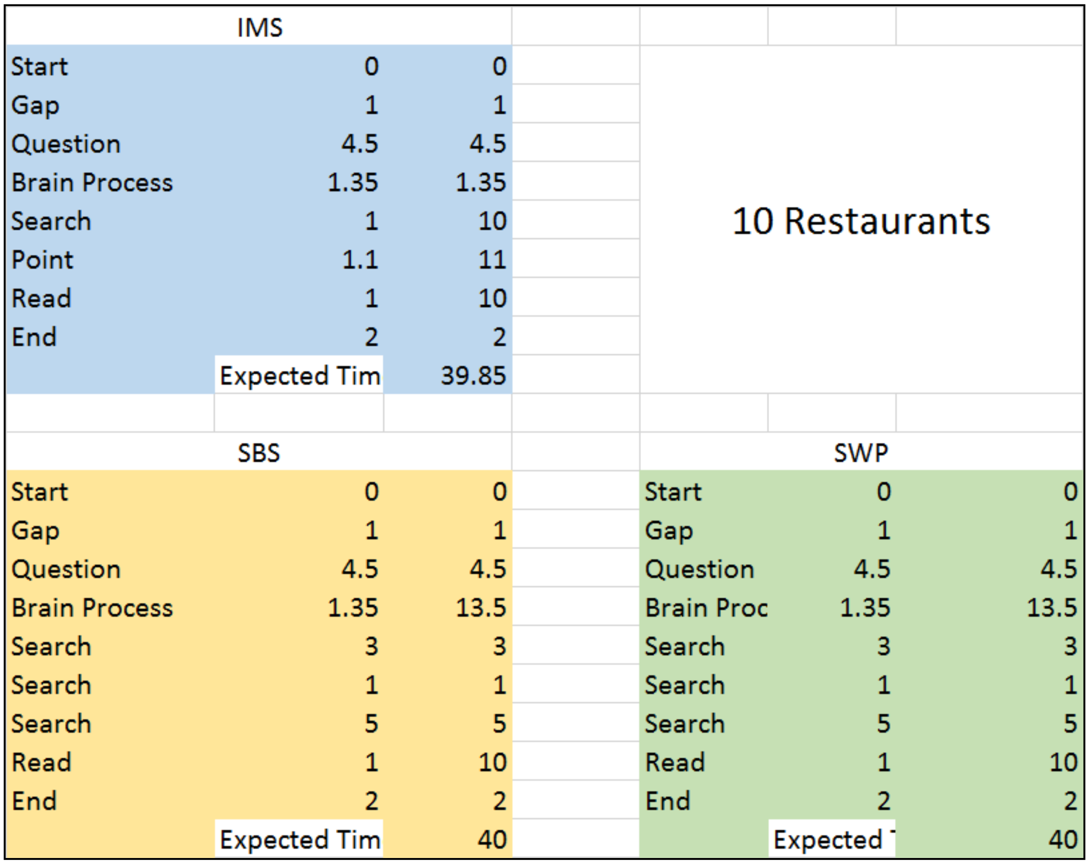
Start	0				
Gap	1				
Q1	4.4	Q3	12.0	Q5	4.0
Brain Proc	1.35	Brain Proc	1.4	Brain Proc	1.35
Search	15	Search	3.0	Search	3
		Point	0.2	Point	0.2
Read	1	Read	1.0	Read	1
Gap	1	Gap	1.0	Gap	1
Q2	4.4	Q4	4.0	Q6	6.7
Brain Proc	1.35	Brain Proc	1.4	Brain Proc	1.35
Search	7	Search	7.0	Search	4
Read	1	Read	1.0	Point	2.2
Gap	1	Gap	1.0	Read	1
				END	2
				Expected	99.2

SWP

Start	0				
Gap	1				
Q1	4.4	Q3	12	Q5	4.0
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	15	Search	3	Search	1
		Point	3	Point	0
Read	1	Read	1	Read	1
Gap	1	Gap	1	Gap	1
Q2	4.4	Q4	4.0	Q6	6.7
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	7	Search	7	Search	2
Read	1	Read	1	Point	1.1
Gap	1	Gap	1	Read	1
				END	2
				Expected	96.7

SBS

Start	0				
Gap	1				
Q1	4.4	Q3	12	Q5	4
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	15	Search	3	Search	1
		Point	3	Point	0
Read	1	Read	1	Read	1
Gap	1	Gap	1	Gap	1
Q2	4.4	Q4	4.0	Q6	6.7
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	7	Search	7	Search	4
Read	1	Read	1	Point	1.1
Gap	1	Gap	1	Read	1
				END	2
				Expected	98.7

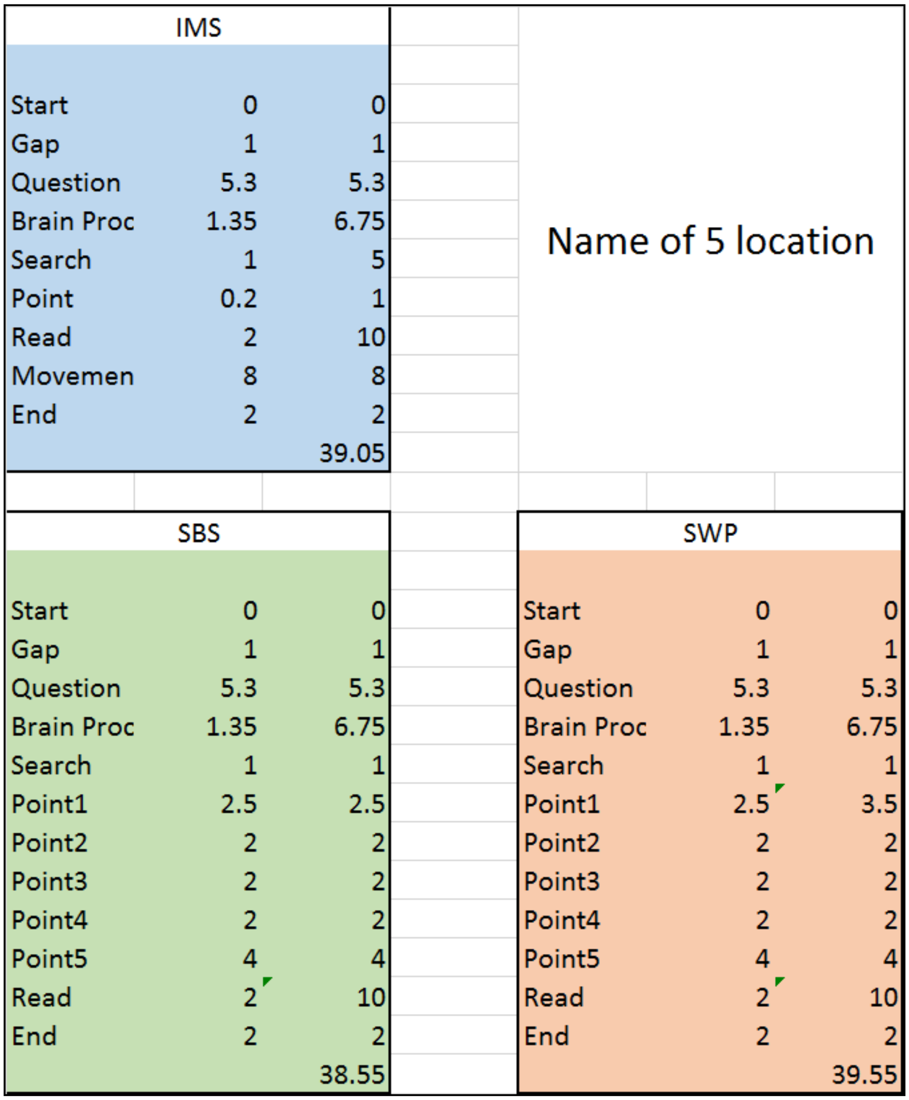


10 Restaurants

IMS		
Start	0	0
Gap	1	1
Question	4.5	4.5
Brain Process	1.35	1.35
Search	1	10
Point	1.1	11
Read	1	10
End	2	2
	Expected Tim	39.85

SBS		
Start	0	0
Gap	1	1
Question	4.5	4.5
Brain Process	1.35	13.5
Search	3	3
Search	1	1
Search	5	5
Read	1	10
End	2	2
	Expected Tim	40

SWP		
Start	0	0
Gap	1	1
Question	4.5	4.5
Brain Proc	1.35	13.5
Search	3	3
Search	1	1
Search	5	5
Read	1	10
End	2	2
	Expected	40



IMS

Start	0	0
Gap	1	1
Question	5.3	5.3
Brain Proc	1.35	6.75
Search	1	5
Point	0.2	1
Read	2	10
Movemen	8	8
End	2	2
		39.05

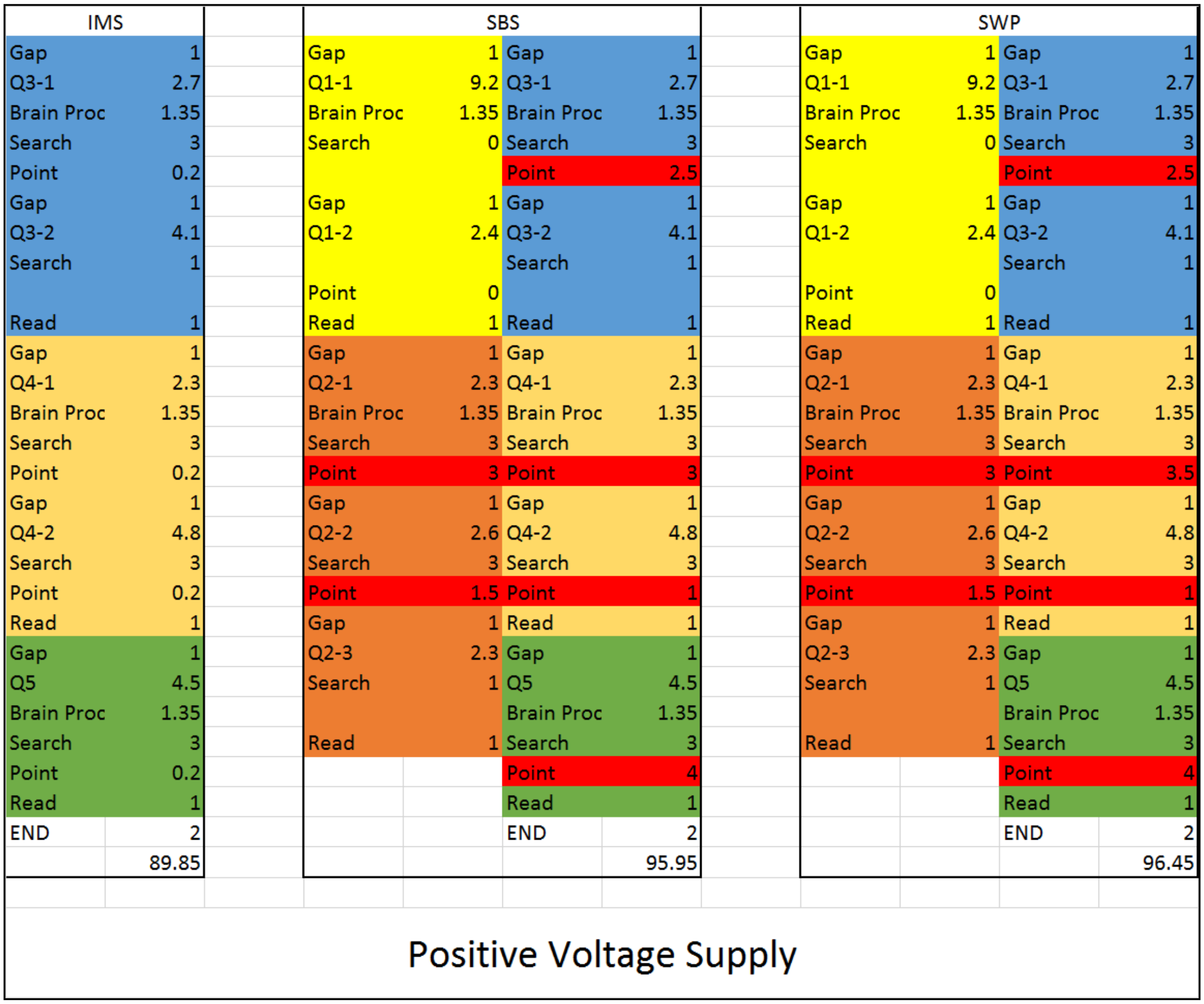
Name of 5 location

SBS

Start	0	0
Gap	1	1
Question	5.3	5.3
Brain Proc	1.35	6.75
Search	1	1
Point1	2.5	2.5
Point2	2	2
Point3	2	2
Point4	2	2
Point5	4	4
Read	2	10
End	2	2
		38.55

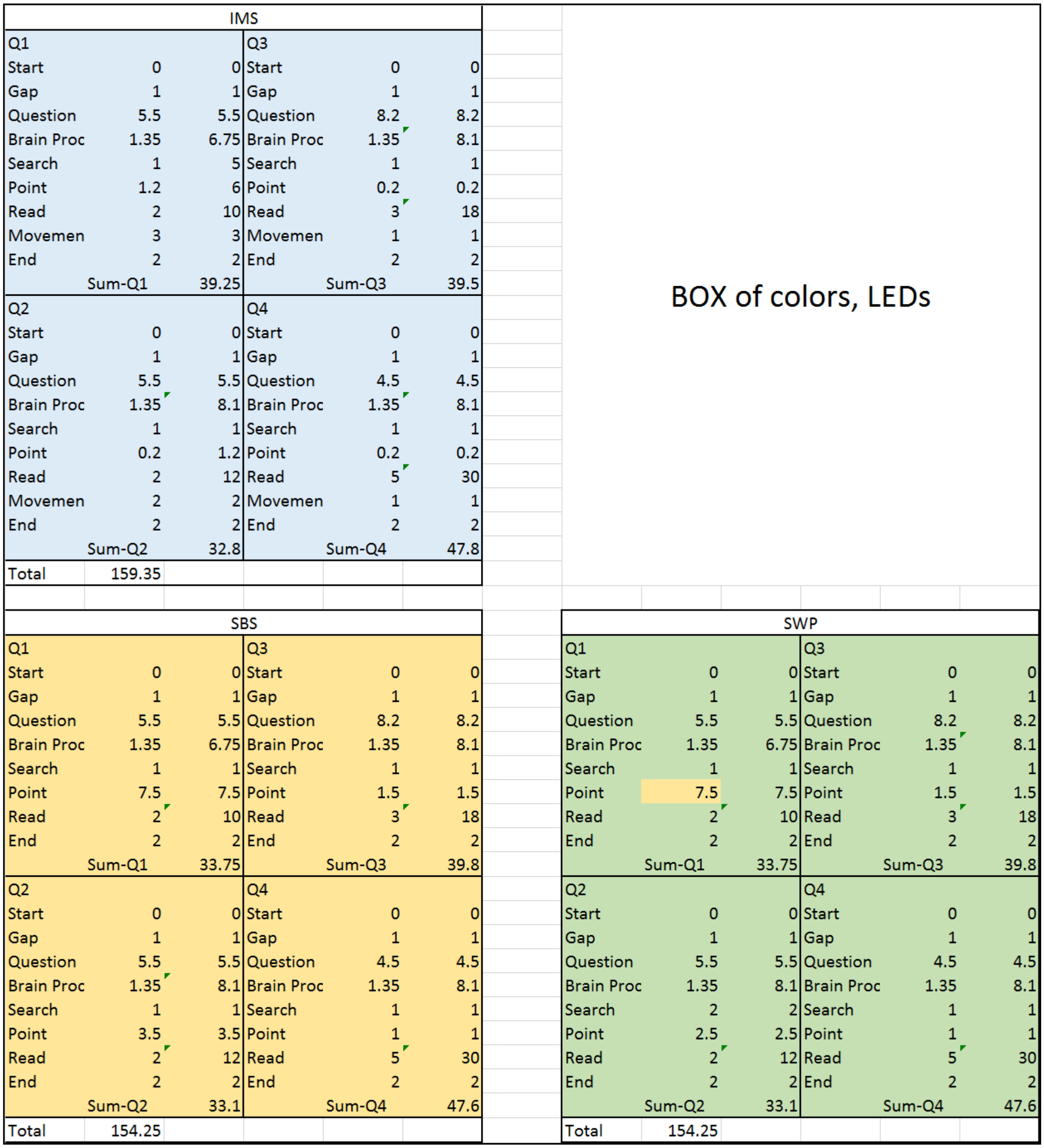
SWP

Start	0	0
Gap	1	1
Question	5.3	5.3
Brain Proc	1.35	6.75
Search	1	1
Point1	2.5	3.5
Point2	2	2
Point3	2	2
Point4	2	2
Point5	4	4
Read	2	10
End	2	2
		39.55



IMS		SBS				SWP			
Gap	1	Gap	1	Gap	1	Gap	1	Gap	1
Q3-1	2.7	Q1-1	9.2	Q3-1	2.7	Q1-1	9.2	Q3-1	2.7
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	3	Search	0	Search	3	Search	0	Search	3
Point	0.2			Point	2.5			Point	2.5
Gap	1	Gap	1	Gap	1	Gap	1	Gap	1
Q3-2	4.1	Q1-2	2.4	Q3-2	4.1	Q1-2	2.4	Q3-2	4.1
Search	1			Search	1			Search	1
		Point	0			Point	0		
Read	1	Read	1	Read	1	Read	1	Read	1
Gap	1	Gap	1	Gap	1	Gap	1	Gap	1
Q4-1	2.3	Q2-1	2.3	Q4-1	2.3	Q2-1	2.3	Q4-1	2.3
Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35	Brain Proc	1.35
Search	3	Search	3	Search	3	Search	3	Search	3
Point	0.2	Point	3	Point	3	Point	3	Point	3.5
Gap	1	Gap	1	Gap	1	Gap	1	Gap	1
Q4-2	4.8	Q2-2	2.6	Q4-2	4.8	Q2-2	2.6	Q4-2	4.8
Search	3	Search	3	Search	3	Search	3	Search	3
Point	0.2	Point	1.5	Point	1	Point	1.5	Point	1
Read	1	Gap	1	Read	1	Gap	1	Read	1
Gap	1	Q2-3	2.3	Gap	1	Q2-3	2.3	Gap	1
Q5	4.5	Search	1	Q5	4.5	Search	1	Q5	4.5
Brain Proc	1.35			Brain Proc	1.35			Brain Proc	1.35
Search	3	Read	1	Search	3	Read	1	Search	3
Point	0.2			Point	4			Point	4
Read	1			Read	1			Read	1
END	2			END	2			END	2
	89.85				95.95				96.45

Positive Voltage Supply



IMS

Q1			Q3		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	8.2	8.2
Brain Proc	1.35	6.75	Brain Proc	1.35	8.1
Search	1	5	Search	1	1
Point	1.2	6	Point	0.2	0.2
Read	2	10	Read	3	18
Movemen	3	3	Movemen	1	1
End	2	2	End	2	2
	Sum-Q1	39.25		Sum-Q3	39.5
Q2			Q4		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	4.5	4.5
Brain Proc	1.35	8.1	Brain Proc	1.35	8.1
Search	1	1	Search	1	1
Point	0.2	1.2	Point	0.2	0.2
Read	2	12	Read	5	30
Movemen	2	2	Movemen	1	1
End	2	2	End	2	2
	Sum-Q2	32.8		Sum-Q4	47.8
Total	159.35				

BOX of colors, LEDs

SBS

Q1			Q3		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	8.2	8.2
Brain Proc	1.35	6.75	Brain Proc	1.35	8.1
Search	1	1	Search	1	1
Point	7.5	7.5	Point	1.5	1.5
Read	2	10	Read	3	18
End	2	2	End	2	2
	Sum-Q1	33.75		Sum-Q3	39.8
Q2			Q4		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	4.5	4.5
Brain Proc	1.35	8.1	Brain Proc	1.35	8.1
Search	1	1	Search	1	1
Point	3.5	3.5	Point	1	1
Read	2	12	Read	5	30
End	2	2	End	2	2
	Sum-Q2	33.1		Sum-Q4	47.6
Total	154.25				

SWP

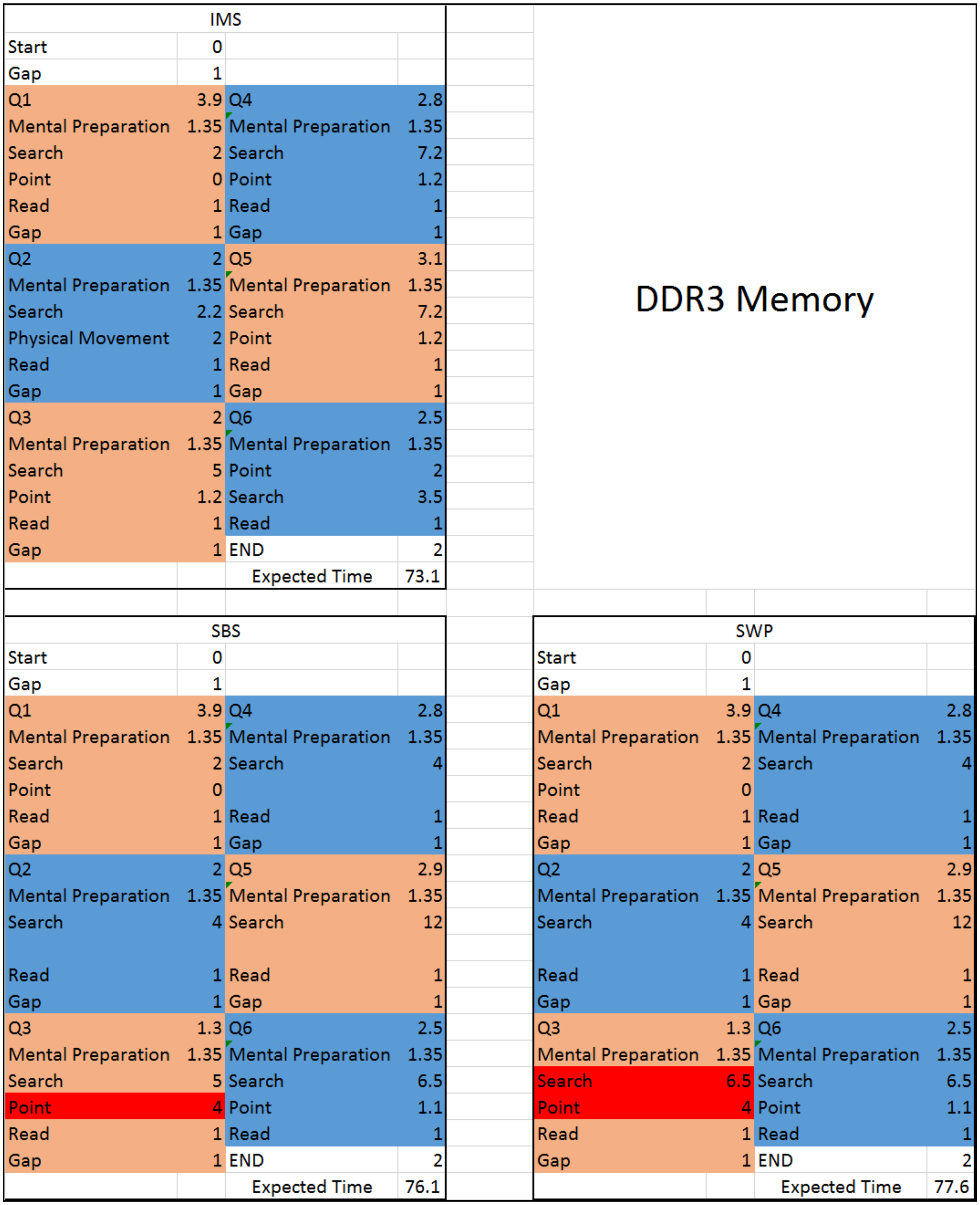
Q1			Q3		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	8.2	8.2
Brain Proc	1.35	6.75	Brain Proc	1.35	8.1
Search	1	1	Search	1	1
Point	7.5	7.5	Point	1.5	1.5
Read	2	10	Read	3	18
End	2	2	End	2	2
	Sum-Q1	33.75		Sum-Q3	39.8
Q2			Q4		
Start	0	0	Start	0	0
Gap	1	1	Gap	1	1
Question	5.5	5.5	Question	4.5	4.5
Brain Proc	1.35	8.1	Brain Proc	1.35	8.1
Search	2	2	Search	1	1
Point	2.5	2.5	Point	1	1
Read	2	12	Read	5	30
End	2	2	End	2	2
	Sum-Q2	33.1		Sum-Q4	47.6
Total	154.25				

Color Streets

IMS			
Start	0		
Gap	1		
Q1	4.2	Q4	4.2
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	0.2	Point	0.2
Read	2	Read	2
Search	2	Search	2
Point	0.2	Point	0.2
Read	2	Read	2
Gap	1	Gap	1
Q2	4.2	Q5	4.4
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	0.2	Point	0.2
Read	2	Read	2
Search	2	Search	2
Point	0.2	Point	0.2
Read	2	Read	2
Gap	1	Gap	1
Q3	4.4	Q6	5
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	5
Point	0.2	Point	0.4
Read	2	Show	2
Search	2	END	2
Point	0.2		86.9
Read	2		
Gap	1		

SBS			
Start	0		
Gap	1		
Q1	4.2	Q4	4.2
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	1	Point	0.5
Read	2	Read	2
Search	2	Search	2
Point	3	Point	3
Read	2	Read	2
Gap	1	Gap	1
Q2	4.2	Q5	4.4
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	2	Point	1.5
Read	2	Read	2
Search	2	Search	2
Point	3.5	Point	3.5
Read	2	Read	2
Gap	1	Gap	1
Q3	4.4	Q6	5
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	5
Point	1	Point	6
Read	2	Show	2
Search	2	END	2
Point	2		111.5
Read	2		
Gap	1		

SWP			
Start	0		
Gap	1		
Q1	4.2	Q4	4.2
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	1	Point	0.5
Read	2	Read	2
Search	2	Search	2
Point	4	Point	4
Read	2	Read	2
Gap	1	Gap	1
Q2	4.2	Q5	4.4
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	1
Point	2	Point	1.5
Read	2	Read	2
Search	4	Search	2
Point	5.5	Point	4.5
Read	2	Read	2
Gap	1	Gap	1
Q3	4.4	Q6	5
Brain Proc	1.35	Brain Proc	1.35
Search	1	Search	5
Point	1	Point	6
Read	2	Show	2
Search	5	END	2
Point	3.5		123
Read	2		
Gap	1		



DDR3 Memory

IMS

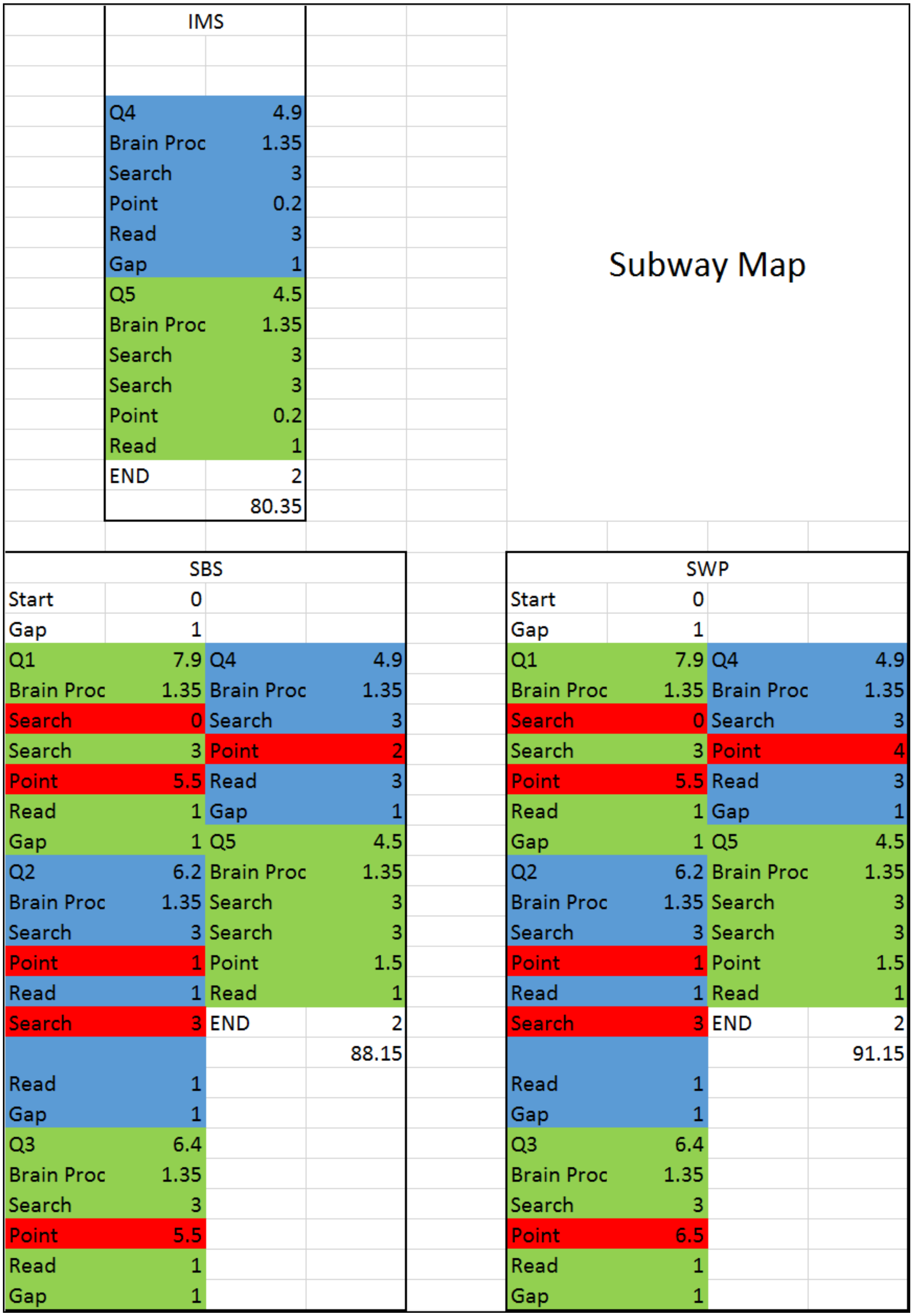
Start	0		
Gap	1		
Q1	3.9	Q4	2.8
Mental Preparation	1.35	Mental Preparation	1.35
Search	2	Search	7.2
Point	0	Point	1.2
Read	1	Read	1
Gap	1	Gap	1
Q2	2	Q5	3.1
Mental Preparation	1.35	Mental Preparation	1.35
Search	2.2	Search	7.2
Physical Movement	2	Point	1.2
Read	1	Read	1
Gap	1	Gap	1
Q3	2	Q6	2.5
Mental Preparation	1.35	Mental Preparation	1.35
Search	5	Point	2
Point	1.2	Search	3.5
Read	1	Read	1
Gap	1	END	2
		Expected Time	73.1

SBS

Start	0		
Gap	1		
Q1	3.9	Q4	2.8
Mental Preparation	1.35	Mental Preparation	1.35
Search	2	Search	4
Point	0		
Read	1	Read	1
Gap	1	Gap	1
Q2	2	Q5	2.9
Mental Preparation	1.35	Mental Preparation	1.35
Search	4	Search	12
Read	1	Read	1
Gap	1	Gap	1
Q3	1.3	Q6	2.5
Mental Preparation	1.35	Mental Preparation	1.35
Search	5	Search	6.5
Point	4	Point	1.1
Read	1	Read	1
Gap	1	END	2
		Expected Time	76.1

SWP

Start	0		
Gap	1		
Q1	3.9	Q4	2.8
Mental Preparation	1.35	Mental Preparation	1.35
Search	2	Search	4
Point	0		
Read	1	Read	1
Gap	1	Gap	1
Q2	2	Q5	2.9
Mental Preparation	1.35	Mental Preparation	1.35
Search	4	Search	12
Read	1	Read	1
Gap	1	Gap	1
Q3	1.3	Q6	2.5
Mental Preparation	1.35	Mental Preparation	1.35
Search	6.5	Search	6.5
Point	4	Point	1.1
Read	1	Read	1
Gap	1	END	2
		Expected Time	77.6

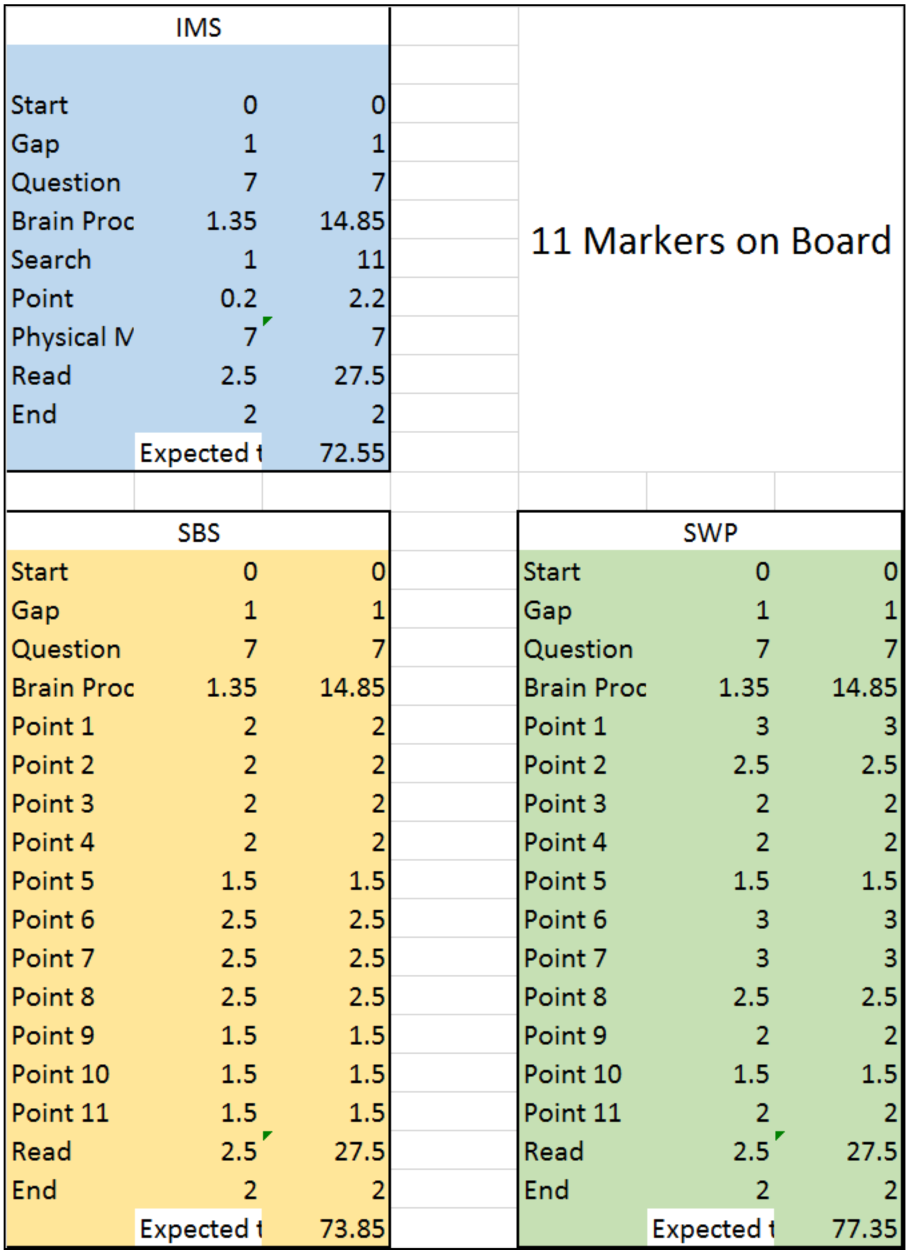


Subway Map

IMS	
Q4	4.9
Brain Proc	1.35
Search	3
Point	0.2
Read	3
Gap	1
Q5	4.5
Brain Proc	1.35
Search	3
Search	3
Point	0.2
Read	1
END	2
	80.35

SBS			
Start	0		
Gap	1		
Q1	7.9	Q4	4.9
Brain Proc	1.35	Brain Proc	1.35
Search	0	Search	3
Search	3	Point	2
Point	5.5	Read	3
Read	1	Gap	1
Gap	1	Q5	4.5
Q2	6.2	Brain Proc	1.35
Brain Proc	1.35	Search	3
Search	3	Search	3
Point	1	Point	1.5
Read	1	Read	1
Search	3	END	2
			88.15
Read	1		
Gap	1		
Q3	6.4		
Brain Proc	1.35		
Search	3		
Point	5.5		
Read	1		
Gap	1		

SWP			
Start	0		
Gap	1		
Q1	7.9	Q4	4.9
Brain Proc	1.35	Brain Proc	1.35
Search	0	Search	3
Search	3	Point	4
Point	5.5	Read	3
Read	1	Gap	1
Gap	1	Q5	4.5
Q2	6.2	Brain Proc	1.35
Brain Proc	1.35	Search	3
Search	3	Search	3
Point	1	Point	1.5
Read	1	Read	1
Search	3	END	2
			91.15
Read	1		
Gap	1		
Q3	6.4		
Brain Proc	1.35		
Search	3		
Point	6.5		
Read	1		
Gap	1		

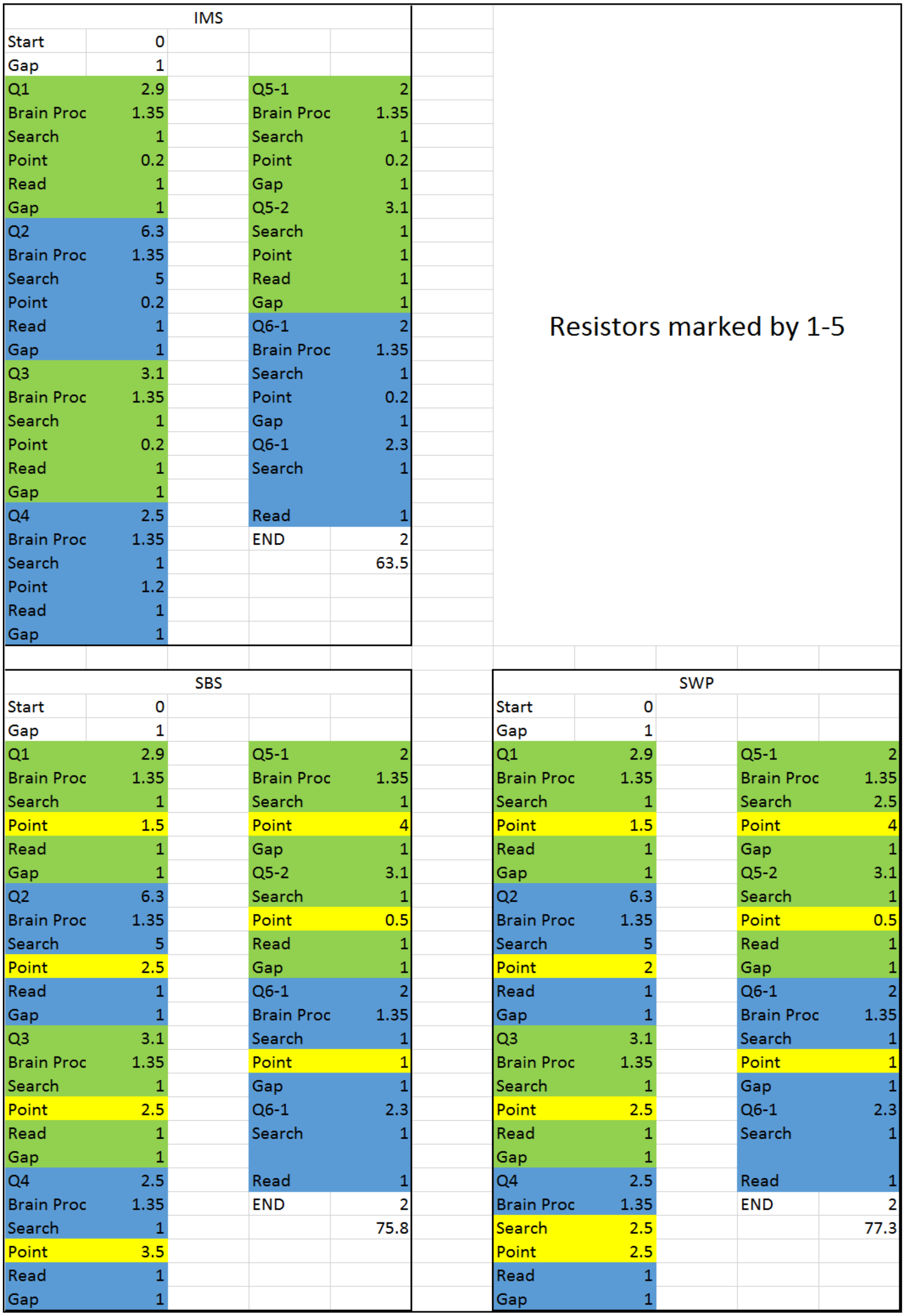


11 Markers on Board

IMS		
Start	0	0
Gap	1	1
Question	7	7
Brain Proc	1.35	14.85
Search	1	11
Point	0.2	2.2
Physical M	7	7
Read	2.5	27.5
End	2	2
	Expected t	72.55

SBS		
Start	0	0
Gap	1	1
Question	7	7
Brain Proc	1.35	14.85
Point 1	2	2
Point 2	2	2
Point 3	2	2
Point 4	2	2
Point 5	1.5	1.5
Point 6	2.5	2.5
Point 7	2.5	2.5
Point 8	2.5	2.5
Point 9	1.5	1.5
Point 10	1.5	1.5
Point 11	1.5	1.5
Read	2.5	27.5
End	2	2
	Expected t	73.85

SWP		
Start	0	0
Gap	1	1
Question	7	7
Brain Proc	1.35	14.85
Point 1	3	3
Point 2	2.5	2.5
Point 3	2	2
Point 4	2	2
Point 5	1.5	1.5
Point 6	3	3
Point 7	3	3
Point 8	2.5	2.5
Point 9	2	2
Point 10	1.5	1.5
Point 11	2	2
Read	2.5	27.5
End	2	2
	Expected t	77.35

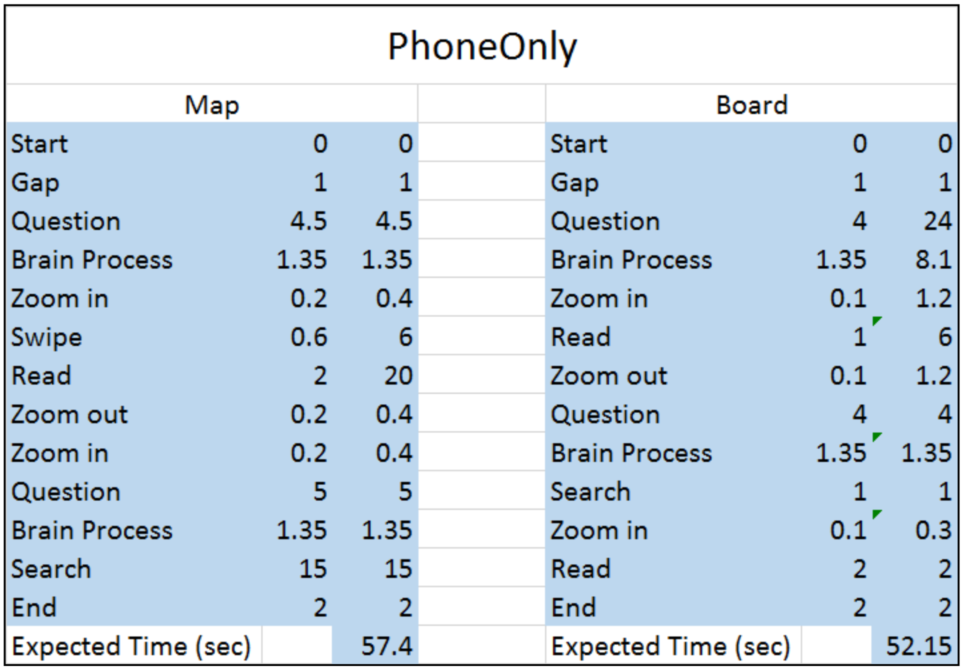


IMS				
Start	0			
Gap	1			
Q1	2.9		Q5-1	2
Brain Proc	1.35		Brain Proc	1.35
Search	1		Search	1
Point	0.2		Point	0.2
Read	1		Gap	1
Gap	1		Q5-2	3.1
Q2	6.3		Search	1
Brain Proc	1.35		Point	1
Search	5		Read	1
Point	0.2		Gap	1
Read	1		Q6-1	2
Gap	1		Brain Proc	1.35
Q3	3.1		Search	1
Brain Proc	1.35		Point	0.2
Search	1		Gap	1
Point	0.2		Q6-1	2.3
Read	1		Search	1
Gap	1			
Q4	2.5		Read	1
Brain Proc	1.35		END	2
Search	1			63.5
Point	1.2			
Read	1			
Gap	1			

Resistors marked by 1-5

SBS				
Start	0			
Gap	1			
Q1	2.9		Q5-1	2
Brain Proc	1.35		Brain Proc	1.35
Search	1		Search	1
Point	1.5		Point	4
Read	1		Gap	1
Gap	1		Q5-2	3.1
Q2	6.3		Search	1
Brain Proc	1.35		Point	0.5
Search	5		Read	1
Point	2.5		Gap	1
Read	1		Q6-1	2
Gap	1		Brain Proc	1.35
Q3	3.1		Search	1
Brain Proc	1.35		Point	1
Search	1		Gap	1
Point	2.5		Q6-1	2.3
Read	1		Search	1
Gap	1			
Q4	2.5		Read	1
Brain Proc	1.35		END	2
Search	1			75.8
Point	3.5			
Read	1			
Gap	1			

SWP				
Start	0			
Gap	1			
Q1	2.9		Q5-1	2
Brain Proc	1.35		Brain Proc	1.35
Search	1		Search	2.5
Point	1.5		Point	4
Read	1		Gap	1
Gap	1		Q5-2	3.1
Q2	6.3		Search	1
Brain Proc	1.35		Point	0.5
Search	5		Read	1
Point	2		Gap	1
Read	1		Q6-1	2
Gap	1		Brain Proc	1.35
Q3	3.1		Search	1
Brain Proc	1.35		Point	1
Search	1		Gap	1
Point	2.5		Q6-1	2.3
Read	1		Search	1
Gap	1			
Q4	2.5		Read	1
Brain Proc	1.35		END	2
Search	2.5			77.3
Point	2.5			
Read	1			
Gap	1			



PhoneOnly

Map				Board		
Start	0	0		Start	0	0
Gap	1	1		Gap	1	1
Question	4.5	4.5		Question	4	24
Brain Process	1.35	1.35		Brain Process	1.35	8.1
Zoom in	0.2	0.4		Zoom in	0.1	1.2
Swipe	0.6	6		Read	1	6
Read	2	20		Zoom out	0.1	1.2
Zoom out	0.2	0.4		Question	4	4
Zoom in	0.2	0.4		Brain Process	1.35	1.35
Question	5	5		Search	1	1
Brain Process	1.35	1.35		Zoom in	0.1	0.3
Search	15	15		Read	2	2
End	2	2		End	2	2
Expected Time (sec)		57.4		Expected Time (sec)		52.15