Human Interface: The Future of Wearable Technologies in Daily Use Through the Lens of Interaction & Acceptability

A Thesis Submitted to the Faculty of the Industrial Design Department
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Table of Contents

List of Images & Tables

Human Interface: The Future of Wearable Technologies in Daily Use Through the Lens of Interaction & Acceptability

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A new stage of computing technology at the beginning of the 21st Century, linked the personal and the pervasive through a combination of mobile technology & ambient Intelligence (AmI) (Birringer J & Danjoux M. 2009). However, the traditional approach of “adapting the machine in front of you,” which was the primary focus of technology devices in 1992 and can be very effective in the personal workstation model today, breaks down as we move to a future of ubiquitous computing.

There is an opportunity to leverage wearable technologies (WT) within ubiquitous computing system environments, that use AmI, to enhance human experiences in daily life and merge this technology into social culture. This thesis investigates dimensions of interaction and user experience of WT and its effect on user acceptability, with the eventual development of WT devices within an AmI system, that improve the experience of daily activities. The goal is to create a pervasive system that makes technology more accessible to people by focusing on environment interaction instead of device interaction.

Keywords: *Wearable Technology, User acceptability, User interaction, User Experience, Ubiquitous computing, Ambient Intelligence, Machine Learning, Human-computer Interface.*

Introduction

In his paper "The computer of the 21st century", Mark Weiser (1991) first used the term "ubiquitous computing" (Ubicomp/UC) to describe the Paolo Alto Research Center's (PARC) vision of reinventing the future. Instead of extending the old computer revolution into new widgets and gadgets, they were at the dawn of a whole new revolution. Weiser and his PARC colleagues were keen to steer attention away from the technological devices and in a different direction, as they claimed, towards people themselves.

Defining Ubicomp as an essentially human-centered approach, Weiser and his colleagues construct a story of dualisms that is based on the concept of invisibility (Kerasidou. & Charalampia, X. 2017). The idea was to move focus away from the machines and the technical, and instead concentrate on people and their social environment. In Weiser's words: "Machines that fit the human environment instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods." Weiser's fundamental premise; namely, the premise that invisibility, a key characteristic of his vision of ubiquitous computing, is 'a fundamental consequence not of technology but human psychology', It focuses innovation to what is really important in life 'away from emphasis on the machine and back to the person and his or her life in the world of work, play, and home'. He goes on to mention that "The real power of the concept comes not from any one of these devices—it emerges from the interaction of all of them."

There is no longer a need for a single device that does everything, rather there exists a network of devices all around the user that are in constant communication with the user and each other to accomplish tasks that the user needs, as and when needed. Weiser's essay promises technologies that will disappear and ''weave themselves into the fabric of everyday life'' (Bradzell, J. et al. 2014). It fleshes out this promise by exploring several speculations about the technologies, such as shrinking and cheaper processors that would power computational objects to enable this weaving. Five years later, Weiser and colleague John Seely Brown (1996) updated this vision in an essay called ‘‘The Coming Age of Calm Technology,’’ in which the two authors develop the speculative dimension of the ubicomp vision by imagining the implications of people having to interact with hundreds of computers that surround them at any given time.

Weiser & Brown (1996) propose a new model of human-computer interaction, which they dub ‘‘calm technology.’’ The idea is that with hundreds of processors per person, technology cannot be the center of our attention the way it is today, or it will overwhelm us. Instead, they argue that it should enter and exit our attention gracefully, moving from periphery to the center of attention as needed. Calm technologies will alter human perception itself, by extending our peripheral reach.

Most of the predictions and speculations that the authors made about the advancements in technology that allow the possibility of a world in which ubiquitous computing is a reality, are coming true today. Until recently, mobile computing has been very much confined to conventional computing form factors, i.e., laptops, tablets and smartphones, which have achieved a standardized design in outlook and shape. However, most industries are recognizing the importance and need for a shift in the way technology is consumed by the masses. In their predictions for trends in 2018, Fjord, a leading design and innovation company, predicts that

> “Digital is no longer the centerpiece of experience. Emphasis is shifting onto how best to use it as an invisible enabler of physical and sensory experiences. As interactions with users evolve from periodic engagements via a screen to consistent, connected experiences, organizations must create new services that are deeply integrated in the physical world” (trends.fjordnet.com).

The more a technology develops, the more it becomes a part of everyday life (Çigdem E., n.d). Wearable Technology (WT) could be an opportunity space to aid this paradigm shift of how users consume and interact with technology that is all around them.

At this stage, thought needs to be given as to how these systems will fit into our current understanding of technology and the necessary changes in standardized (over the past century) interactions and experiences required, for this ubiquitous technology to reach its potential and indeed become the norm of technology in society.

Thesis Statement

Over the past decade, computing technology has evolved by great leaps and bounds. The interactions for this technology however have not and we still stick to the age-old idea of *"adapting to the machine in front of you"*. There is need for a more meaningful interaction and experience with computing technology that makes humans the center of interaction.

Research Areas of Interest

This thesis aims at developing an improved method of interaction with technology within Ubiquitous Computing System (UC) Environments to enhance human experiences and create a more intuitive and natural system of interaction using Wearable Technology (WT) in the home environment, thus making it more

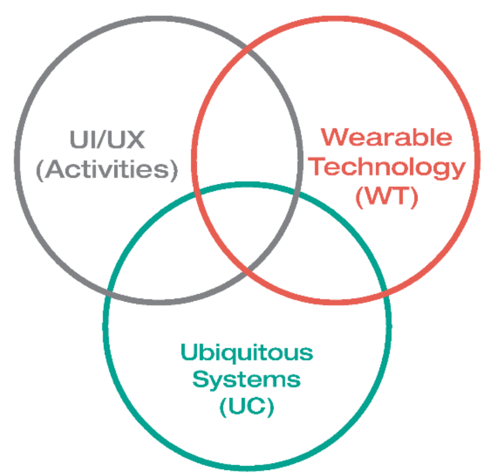

Figure 1: Areas of Research

accessible by focusing on environment interaction instead of device interaction.

The union of these areas is the space in which my thesis topic lies. It focuses on identifying a means of interaction with technology that is natural and intuitive by focusing on human action rather than screen interfaces.

Umbrella Question & Sub Questions

How might we make Interaction & Experience (IU/UX) more meaningful within a Ubiquitous Computing (UC) System using Wearable Technology (WT)?

A. What are the effects of various human-computer interactions (HCI) on user perception & acceptance of WT within society culture?
B. How can WT become an integral part of everyday life within AmI, through the lens of fashion & function?
C. Can "sensing" achieve better Quality of Life (QOL) & improve adoption rate within AmI?
D. What role can AmI play in the adoption of WT?

Theoretical Framework

For this thesis, I am using an Interpretivist Paradigm of research. An interpretive paradigm allows researchers to view the world through the perceptions and experiences of the participants.

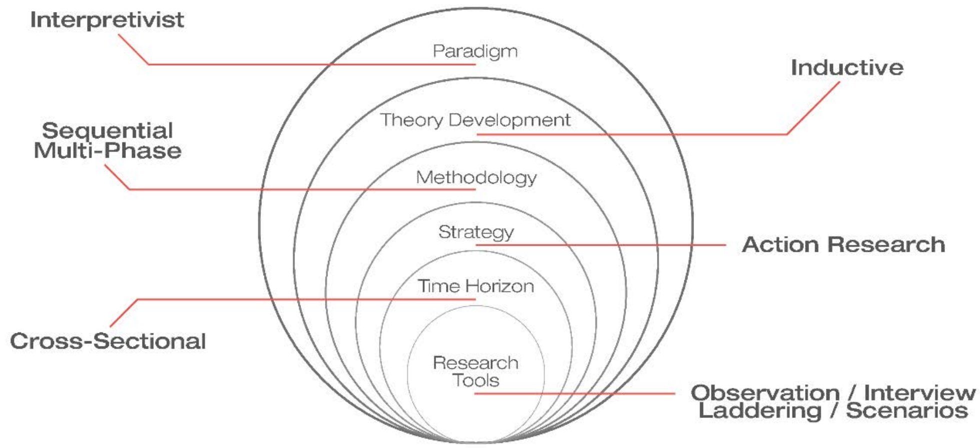

Figure 2: Research Onion

In seeking the answers for research, the investigator who follows an Interpretive Paradigm uses those experiences to construct and interpret their understanding from gathered data. Specifically, interpretivism supports scholars in terms of exploring their world by interpreting the understanding of individuals. (Nguyen, T. & Tran, T. 2015)

Research Process

For this thesis, I am using the D3E3 model of design, which is something that I developed during my time at SCAD. It draws inspiration from various other design models that I have used in the past including the I.E.I.D. model used at S.Labs, Bruce Claxton's D.E.S.I.G.N. process and 'Creative Research' methodology by Hilary Collins.

This methodology breaks down the design process into six stages that follow a circular flow. Each adjacent stage shares a step with the previous and acts as a milestone in the process. The model allows you to move to a previous stage, however, progression only happens in the circular flow.

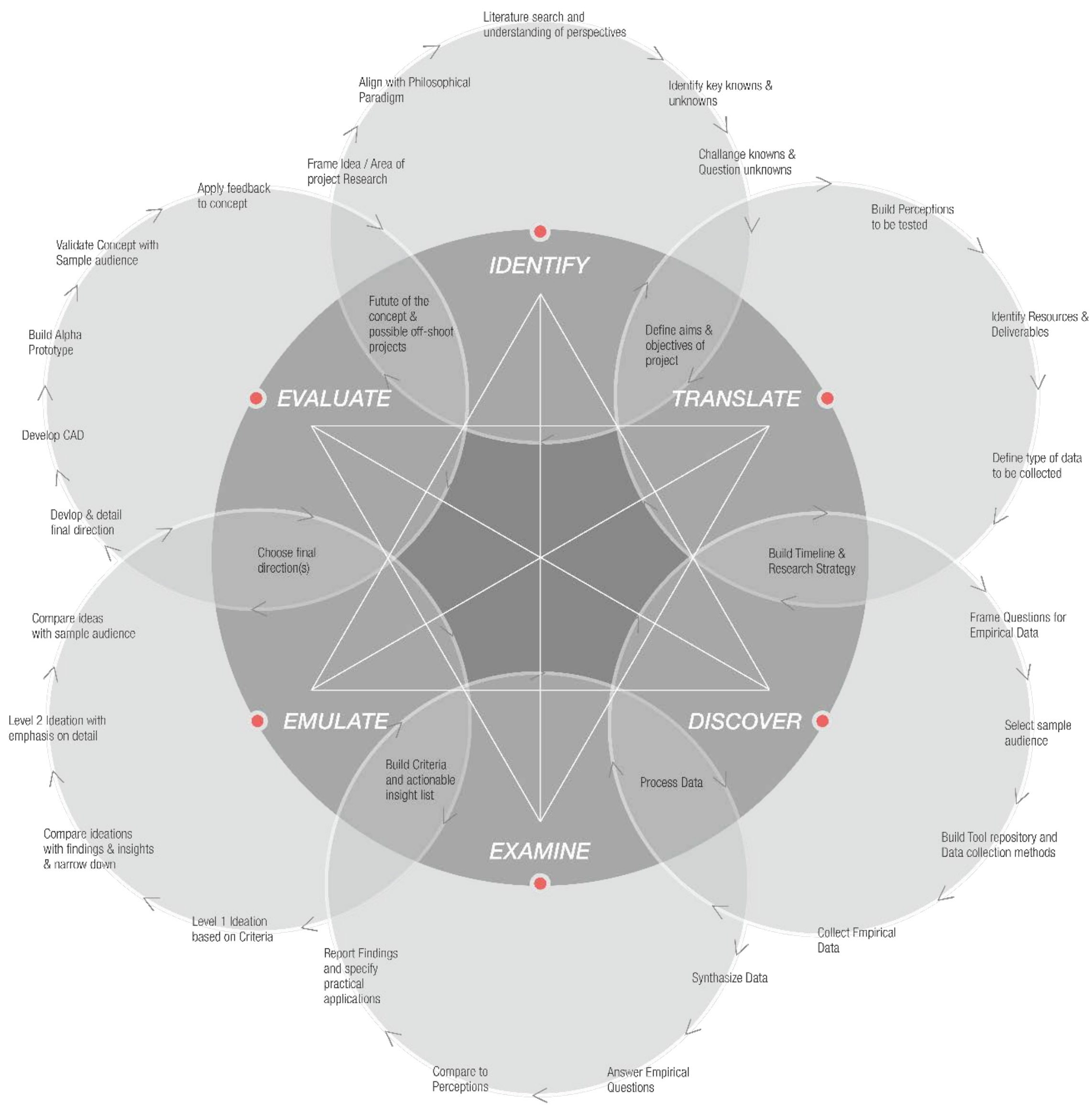

Figure 3: D3E3 Model

Literature Review

Interactions within Ubiquitous Computing & Ambient Intelligence Systems

The ideas envisioned by Weiser in 1991 have evolved into what we today, call Ambient Intelligence (AmI). AmI represents a new generation of user-centered computing environments aiming to find new ways to obtain a better integration of information technology in everyday life devices and activities (Jose, B. et al. 2011). AmI environments have devices of modern life that are fused with computational technology and sensing capabilities. Ideally, people in an AmI environment will not notice these devices, but they will benefit from the services they provide them (Jose, B. et al. 2011).

However, there still exists a platform (which in most cases is made tangible through a screen) in order to use technology spread across an environment, thus defeating the purpose of UC itself and bringing focus back to a central control device that is very visible and becomes the center of interaction.

> "As we move forward from the personal workstation model of computer use to cloud computing and ubiquitous computing, we also need to begin thinking about accessibility in new ways. The traditional approach of "adapting the machine in front of you," which was the primary focus of technology devices in 1992 and can be very effective in the personal workstation model today, breaks down as we move to a future of ubiquitous computing" (Vanderheiden, G.C. 2008).

Limitations of Sensing Mechanisms

Weiser's works on UC, while being very accurate to predict the way technology would evolve, have fallen short in consideration of interaction with these invisible technologies. To overcome limitations in interaction with UC, research efforts in the field of human-computer interaction

(HCI) are invested in augmenting technologies with various “sensing” mechanisms and experimenting with different input modalities that allow them to reach their full potential. One of the most important contributions of technology and the Internet of things (IoT), is the capability of context awareness. The integration of ubiquitous sensing and networking technologies enables the development of new applications in a wide variety of domains. Current research efforts focus on HCI through natural and intuitive modalities including hand/body gestures, face recognition, gaze/eye tracking, bio-signal analysis, speech recognition, activity recognition and their related issues in functionality (Paravati G. & Gatteschi V. 2015). Devices that are augmented with such sensing mechanisms are aware of the people present within environments by reacting to their gestures, actions, and context. While these areas of research help push the boundaries of input functionality and work well by themselves in closed and controlled environments, their sensing capabilities fall short in reading user intension as the network of devices grows to be more complex and include more tasks. These limitations of new HCI methods make them a far from viable solution (at least not in the near future) for sensing user needs and are not ready for commercial application.

It is commonly understood that the goal of any form of technology is to achieve or complete a specific task. In the case of AmI, the environment makes the accomplishment of a task easier by allowing the technology to anticipate the needs of the user and carry the activities out without the user needing to perform an action. A simple example of this is a dustbin that senses an approaching user and opens the lid for the user. Thus, reducing the number of steps required to carry out the task of throwing garbage away. The use of ambient technology helps accomplish tasks more easily, however, as the complexity of the task increases, the process of anticipating or “sensing” user needs also becomes more complex. Consider the task of making breakfast. Here, the sensing of proximity is not enough. These AmI technologies thus need some form of Artificial Intelligence (AI) that helps read situations to predict actions. The area of Machine

Learning (ML) is a core element of AI and helps develop parameters based on past user behavior patterns and context awareness, to define possible decisions that the user would make. Thus, allowing technology to predict needs. To be intelligent, a system that is in a changing environment must have the ability to learn. If it can do so, there is no need for the designer to foresee and provide solutions for every possible situation. The technology adapts to patterns observed from collected data (behavior) to create a "knowledge system" and predict possible scenarios. In "Introduction to Machine Learning", Alpaydin (2014) says:

> "Machine Learning uses the theory of statistics in building mathematical models, because the core task is making inference from a sample."

It is simply an algorithm, based on past data, to identify patterns and predict futures. The most commonly used example of machine learning in AI today is the text prediction function on mobile messaging applications and search engines, where, based on previous vocabulary, sentence structures used (past data) and a knowledge of syntax in a language (context), the system can predict the next word. Thus, machine learning allows technologies to achieve a level of clairvoyance in the decisions that humans make and complete (or suggest) actions without much intervention needed from the user.

Human decision making however, while based on past behaviors and environment context, are also driven by emotion. This element of emotion often leads to irrational choices in decision making that are not based in rational behavior maintained in past actions. Thus, emotion becomes an essential aspect for AI systems to understand and accurately predict user needs. In an article in PR Newswire, C.T.O. of Element Data, Inc. (a decision support software platform), Charles Davis mentioned:

> "Decision making frequently includes an emotional component. Humans make irrational decisions due to extenuating circumstances."

Emotions have a significant impact on perception, decision making, action generation, as well as action execution and control (Liu, B. 2017). Steps have been taken in the area of machine learning to gauge emotion in the form of Emotion-Aware (EA) Computing. Emotion-aware computing allows a sensing device to have the ability to recognize the emotional state of humans and gives an appropriate response to these emotions. Emotion-aware computing can offer benefits and play an essential role in an almost limitless range of applications that involve machine learning (Babiker et al. 2015).

Emotions are commonly recognized by technology in three different ways (Liu, B. 2017). They can be recognized visually by reading facial expressions and gestures of the user with the use of camera sensors that record motion and identify changes that are compared against predetermined parameters to define emotion. The same can be done acoustically through speech recognition and analysis. Changes in tone and pitch act as cues to gauge emotion. The third and more commonly used method of gauging emotion is to record changes in signals of the autonomic nervous system (ANS), where, involuntary changes in the body like pupil dilation, change in heart rate or perspiration can be used to measure emotional condition.

While these methods can sense a change in emotion, given the complexity and range of emotional expressions, much research still needs to be conducted to understand and explain the mechanisms involved in emotion recognition. There can be more than one reason for a change in ANS, and at this stage, research in the area is limited to merely understand if emotion is positive or negative (Liu, B. 2017). It is still difficult to gauge the subtleties and complexities of human emotion. Further, the recognition of emotion may not necessarily help predict action. As discussed earlier, actions driven by emotion are sometimes irrational and may not fit into status quo of perceived behavior patterns that are recognized by EA computing.

As a result of these problems faced, the current Band-Aid solution for limitations in sensing systems is to bridge these shortcomings with the help of the age-old method of input via a platform which requires a central device. But again, as discussed earlier, there needs to be an evolution in the way we interact with AmI to allow it to reach its full potential.

Wearable Technology (WT) in AmI Systems

In their paper, "From the Internet of Things to Embedded Intelligence", the authors (2013) identified two distinct styles of smart object sensing: Object-centric style and Human-centric style. Smart objects belonging to the object-centric type are deployed in the real world and can detect changes in their physical status or/and changes in the surrounding environment. This is the ideal situation that Weiser talks about in his vision of UC. While this is possible using currently available HCI technologies (mentioned earlier), for this form of sensing to work, every object needs to be fitted with sensing devices that can read human gestures & actions in an environment. These technologies still have many shortcomings when it comes to working cohesively outside controlled laboratory environments.

The second (human-centric style of sensing) category focuses on the need of a device that acts as a personal companion that guides the user through a smart environment by acting as an intermediate device that communicates with others. Today this intermediate device has taken the form of Smartphones and Laptops. As discussed earlier, however, these age-old ideas of a personal workstation are losing value in an age where technology is spread around the user and behave as enablers of stagnation to the evolution of technology becoming invisible. One cannot deny that, given the current stage of sensing technology we are in, the second category is more viable as a solution and there still is a need for an intermediate device to intervene for smoother interaction and better sensing. There is, therefore, a need for a device that replaces the age-old idea of a workstation that acts as an identifier and translator on the user's behalf, thus making the interaction smoother. Wearable Technology (WT) can play the role of these intermediate devices.

Wearable technology is a form of Assistive technology that is used to increase, maintain, or improve functional capabilities to make the completion of a task easier. It can be broadly defined as any form of technology that that is worn by a user. Today they most popularly exist in the form of smart device companions (smart watches) and act as mirrors of the smartphones that they are assisting. They consist of a number of sensors that aid functionality of a smartphone and often act as remote controls to the device they assist. This idea of a wearable remote control can be applied to an AmI system where a wearable assists the sensing process to ease the need for sensing capabilities of AmI devices. Thus, replacing the need of Ami to rely on a platform for input of user needs.

A combination of the two styles of sensing, where the qualities of environment sensing are still predominant (object-centric) but are helped along in the process of sensing with the introduction of a WT device (human-centric), could lead to a more defined system where one solves the problems of the other. We thus move away from a system where humans interact with technology to achieve a goal and move towards a system where technology interacts with humans (through wearables) and achieve the goal. With the assistance of AmI systems, wearables have the opportunity to disappear in the present culture and enter the realm of the status quo, acting as a 2-way receiver that helps us through our daily lives.

Perceptions & Acceptability of WT

In the US, 31.6 million people use wearables at least once a month (Consumer Technology Association. n.d.). This increased to 44.7 million in 2017 and is projected to reach about 59.5 million by 2021 (almost double in 7 years). There is no doubt that this is a fast-growing market and will only keep growing over its 6.4-billion-dollar revenue today (eMarketer, & TechCrunch. n.d.).

A major hindrance to the success of smart wearables, however, is found in its poorly designed and limited user interface (UI). The current interaction paradigm of smart wearables simply mimics the age-old UI of touch screen interaction used in phones. In her paper, Yoon says that to justify the adaptation of such UI, some argue that touchscreen-based interaction is familiar to most users. However, smart wearables are physically much smaller (1/5th size of smartphones), and its wearability must be considered for various situations of on-device interaction. She further mentions:

> “The Adaptation of touchscreen UI and an awkward relationship with a paired smartphone, has resulted in current smart wearables being hardly considered a fully functional standalone device, but rather a secondary and auxiliary device” (Yoon, H. et al. 2016).

Furthermore, while Bodine and Gemperle (2003) claim that perceptions of functionality and comfort are the main dimensions for acceptance of new technologies and pragmatic qualities help the user understand that a product functions well, they do not necessarily prove that a device will fit into what is considered the status quo of current society. Raymond Loewy's MAYA (Most Advanced Yet Accessible) principle gives us insight into devices like the Apple Google Glasses that did not fit into the user's present understanding of computing technology.

A wearable, whether used for assistance to a smartphone or in an AmI environment, is more like a piece of clothing than a PC or an appliance, and clothing has been shown to help define identity and supply clues to categorize oneself and others in the culture (Kelly et.al., 2016). A significant departure from what is considered normal in current society can lead to the rejection of the technology. Thus, hedonic qualities of technology are likely to play a more influential role in technology adoption, especially in the mobile (moving around) context, than utilitarian qualities. An example of this is shown by Kim K.J. in his paper comparing smart watch forms. Round screens, despite their negative effect on perceived control, can lead to a higher acceptance of smartwatches by promoting the hedonic (conforming to the accepted) qualities of the device's form & fit. This does not mean that utility is not an important element for these devices. Incorporating hedonic and utilitarian qualities simultaneously into the design of the wearables are extremely important for creating positive first impressions. As a result, manufacturers should continue to strategically plan the enhancement of controllability of round screens, as Samsung has attempted with their rotating bezel, rather than neglecting utilitarian elements and focusing solely on the hedonic qualities of smartwatches.

This is where the incorporation of fashion thinking becomes a critical element in the development of interaction with the device. If users of wearable technology expect to experience these devices in similar ways as their clothes and accessories, the way to design them should then be inspired by fashion design and fashion practices.

There is also the reaction of human and societal culture that needs to be taken into consideration when developing new forms of interaction for WT. For Example, in their paper on user perceptions of smart glasses, Hakkila et al. show through their findings that the use of smart glasses could have a negative effect on the face-to-face interaction with the people present and divert the attention away from the social situation. Privacy concerns were also mentioned, mostly in the context of assumptions other people might be drawing about the expected use of the device. Several participants mentioned that they were concerned that the nearby people would think them doing something unethical or forbidden with the glass. Complexity & size of products create negative use experiences and resulted in rejection by users. Small and subtle gestures that go unnoticed, on the other hand, are socially more acceptable.

These papers by Kelly (2016), Hakkila (2015) & Kim (2016) talk at length about hedonic qualities & the rejection of devices that require actions that do not fit the status quo of society. However, they do not shed light on the interactions with the devices themselves. There is no way to gauge the level of acceptance & comfort that users have in relation to the adoption & use of

WT. There is a need to develop an understanding of what users perceive as the future of communicating with their everyday objects to better understand their level of acceptance of WT.

Incorporation of AmI Systems in Everyday Life

As predicted by Weiser over 27 years ago, there has been an emergence in development of computing technology that fits into the environment of the user instead of forcing the user to enter theirs, in the form of AmI systems within smart spaces. While these AmI systems have begun incorporating themselves into various smart spaces, there is great potential for it to influence activities in everyday life making technology more accessible to people by focusing on environment interaction instead of device interaction. However, the capabilities of these technologies are still limited regarding "sensing" & prediction of human needs. As a result, there is still a need for human interaction with an interface. Wearable Technology can be a possible answer to a replace the platform paradigm and by aiding the sensing process of AmI, thus acting as a key to interact with the environment. The focus then is to understand and develop parameters for the development of WT devices that help AmI reach its full potential and still fit into society seamlessly.

Methodology & Analysis

The methodology is divided into two phases based on the type of data collected and the expected results. This helped segregate data to be analyzed so that it can reveal information that answers specific questions raised by the literature. The data was then combined later to form actionable insights. The phases are laid out in this specific order because certain aspects of data collected from previous phase influenced structure and drove discussions in the next phase. A master analysis of all data collected across the entire research period was done at the end of Phase 2, to compare and highlight possible aspects (actionable Insights) that could influence the design of WT within an AmI system.

A sample set of 33 participants across different age groups & socio-economic backgrounds was selected for this study. This was done to take into consideration, the bias, that the adoption of technology is slower based on an individual's age and position in society (which was an area missing in previous experiments in literature). The results of the study will thus consider the fact that wearables will eventually surpass early adopters (Rogers E. 2003) and be used by everyone. Additionally, the study includes participants from Europe, Asia and North America to take into consideration different cultural practices across the globe to make the results more universally valid.

PHASE 1: Pre-determined Scenario Observation + Interview

Phase 1 focuses on identifying physical forms & types of interaction that people are (and are not) comfortable with, to gain an understanding of levels of acceptance and perception in regard to WT. The research further helps gain insight into how and why these barriers (or pathways) to acceptance exist and the influence of these devices on perceptions of privacy. Apart from gauging user feelings towards form & function, this data also sheds light on the role of "sensing" in relation to decision making & helps determine ideal methods for the same.

While the literature does cover the values of hedonic qualities as compared to utilitarian qualities, the studies are conducted in controlled environments and information is collected in the form of interviews. It does not test these theories in the real world. Furthermore, past experiments focused on one form of wearable at a time and did not take into consideration other wearable forms & body positions. Using observation as a research tool for phase 1, the experiment proves that along with hedonic qualities of form, (which are proven to be major influencers in literature), hedonic qualities of interaction also play a significant role in user acceptance.

Participants were asked to interact with wearable devices in three spaces (home, work & public) with varying social environments for approximately 20 minutes. Reactions of the participant himself and the people around him were recorded. The same experiment was carried out with three different devices that vary in form, size & placement (varying levels of visibility).

Figure 4: Devices used for Phase 1 Observation Experiment (Google Glasses, Apple Watch & Samsung Bluetooth Earphone connected to Google Assistant.) Source: http://www.hindi.itemtutorials.eu/video/-n2_RPw6Ytg http://www.businessinsider.com/apple-watch-sa

As the use of WT in AmI spaces is still limited, the home & workspaces had prototyped interactions that were staged in order to give the participant an experience of what the technology can be capable of in the near future. An example of this, is the use for Light Dependent Resistors (LDR) to automatically turn the lights on when the participant enters a room and suggest that the WT device was responsible for it.

A brief interview with participants regarding the features and perceived functions of the device and its effect on the acceptability of the product, was conducted, prior to and post field observations, to note any changes in their answers. Observation as a data collection tool helped remove the possibility of user bias common in interviews (where the interviewee says something because he believes that this is what the interviewer expects) and resolve the discrepancy between what the user says (or believes) and does.

PHASE 1: Analysis

Data Collected from phase 1 was tabulated and compared against 12 parameters to help gauge user acceptance and identify emergent themes & patterns of interaction. Parameters: P1, P4 & P12 were collected from interview notes while the rest were derived from observation. Participants were rated on a scale of 1 to 3 (low, medium, high) for each parameter. The collected data was then tabulated using a bar graph to visually compare findings recorded in each space.

This research exercise provided insights on two levels. Firstly, the reaction of users and surrounding people revealed information that helped gauge user feelings towards the devices (This was later confirmed by interview responses). Additionally, users performed actions that lead to cues of preferred interaction. Findings from phase 1 were compared to the literature to assess validity of the claims made and cross-check ideal sensing methods perceived by users with those mentioned in the literature to develop an understanding of the best possible fit for the same. In addition to this, findings were also compared to existing methods of boosting adoption to gauge the tipping point at which need of technology outweighs fear of not fitting in.

Tabulated Data from Phase 1

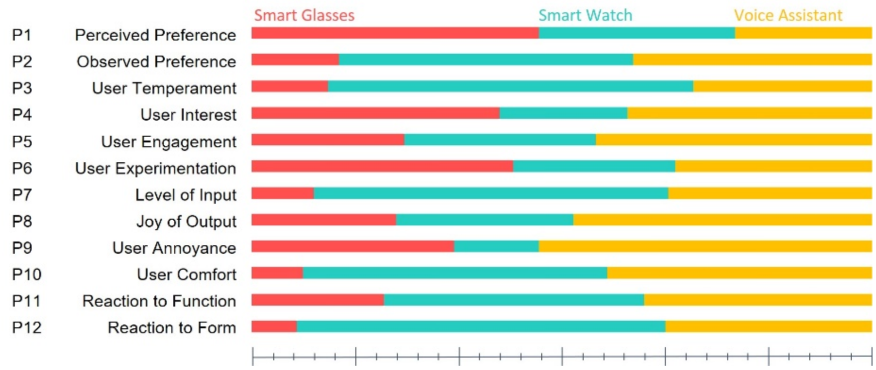

Figure 5: User Observation Analysis in Home Space (1715, Whitaker St., Savannah)

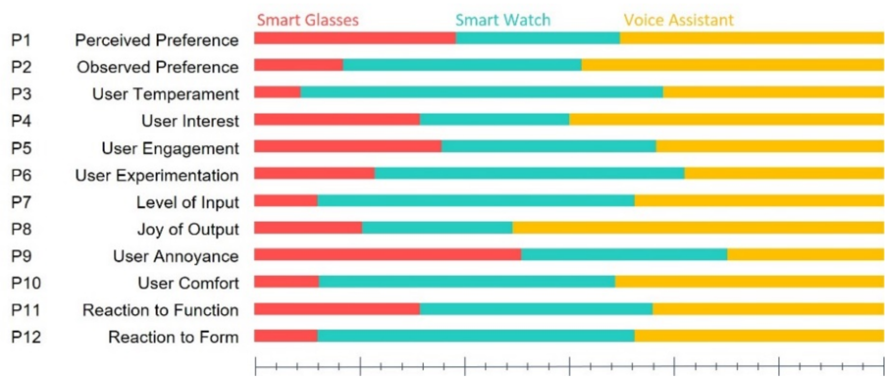

Figure 6: User Observation Analysis in Workspace (Gulfstream Centre for Design, Savannah)

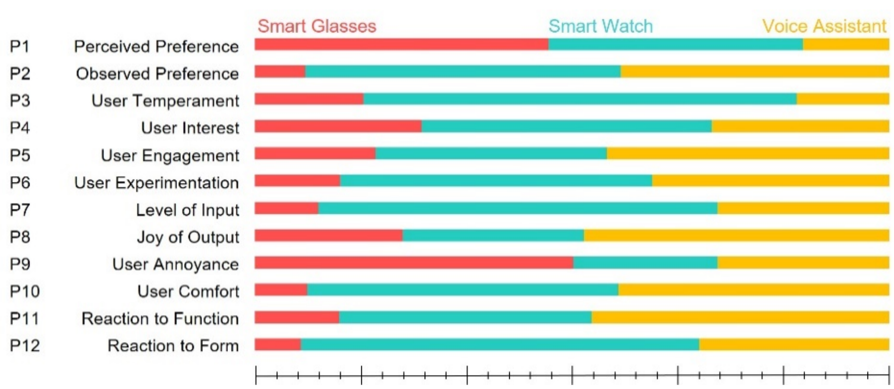

Figure 7: User Observation Analysis in Public Space (Forsyth Park, Savannah)

PHASE 1: Findings

As a starting point, all users grounded the interface and use of these wearables based on previous knowledge of how this kind of technology works. Both the smart watch & voice assistant had shallow learning curves, as interaction with the two was considered more natural. Further analysis of collected data revealed that participants were much more comfortable using wearables in private personal spaces (home & workspaces) as opposed to public spaces. It was observed that using the devices by themselves gave them an opportunity to experiment and make mistakes without anyone judging their actions. Interaction with devices in public spaces were much more conserved.

Most participants perceived the smart glasses as the future of communication technology. However, when using the devices, they were much more inclined to using the smart watch. Furthermore, participants showed a desire to stare at a tangible object (phone) while using WT to root invisible actions in a physical space and showed concern for social image when using the voice assistant as it had no tangible form to interact with. Participants also required a visual feedback that informed them of an action being performed the way they expected it would.

Participants were most comfortable with voice as an input mode (over gesture control) in private spaces even though there were instances where voice input did not work at first attempt. Participants felt that the gestures required as input for WT (smart glasses) were too extravagant and would look 'weird' if performed in public. In situations where an action was done without any user input (lights turning on without any specific action), most participants (24) were pleasantly surprised. They were however inquisitive as to how it worked and how the action was activated.

The preference of invisible smart products is relative. While users prefer devices that do not visually affect social interaction, if the technology was completely hidden from others, they seem to get equally insecure. Devices that create a balance between ambient & physical worlds achieve greater success as compared to those that focus more on either one. Furthermore, familiarity of interaction with technology plays a vital role in the acceptance of a new technology.

PHASE 2: *Participatory Photo Interviews + Scenarios + Laddering*

Most papers on AmI talk about the possible intervention of AmI for the improvement of activities in daily life. However, there is not much discussion about activities & interactions that AmI could positively affect. Phase 2 provides a glimpse of the everyday rituals that participants undertake, the problems they face, and areas that need an improved interaction experience. Phase 2 also focuses on taking information from findings of Phase 1 to help build possible futures of AmI in collaboration with users by identifying where & why change is needed.

Phase 2 began with the use of participatory photo interview as a tool to observe & record the everyday rituals of participants. The exercise involved participants taking photos of inconveniences they faced in daily activities, using mobile phones, across a span of one week and then writing one line describing it. The same was sent to the researcher via text message as and when the activity occurred. As findings from the previous phase showed that users are much more comfortable using new technologies in closed safe spaces, data collection for this phase was narrowed down to areas in and around the home space.

Photographs are not objective and do not present the objective views of the person taking them; they rather depict a way to see or understand an object or context to offer multi-layered meanings (Collins, H. 2017) allowing the data to be not just a list of problems but a larger picture of an inconvenient situation.

One on one interviews were conducted at the end of the week and the photos taken, act as talking points for discussion of the activities in more detail. This interview first discussed problems faced in everyday life based on photos (the interviewer helped push ideas along, based on findings from previous research) and then moved to a discussion of technologies and sensing methods present in the world today. This was then followed by a discussion about scenarios of the perceivable future of AmI in the next 10 Years that can help improve interactions in daily activities.

The interviews ended with a laddering style discussion that dove deeper into why participants want these activities to change and why they think this sort of change will be effective. Scenarios as a research tool helped create what the participants believe is the future of communicating with their everyday objects.

Phase 2: Analysis

The analysis of the photos was not limited to composition, content and design. The context within which photographs were produced and published, their historic timeline and how they were presented (Collins, H. 2017) were also taken into consideration. This was done to understand the communicative intentions and, ultimately, the ideologies and cultural meanings embedded in images. This qualitative research technique provided a means of 'getting inside' the user activities and their context. Photo interviewing helped bridge psychological and physical realities & allowed for a combination of visual and verbal language.

Data collected from Interviews compared practices against one another to highlight commonalities, differences and reveal patterns. Data transcribed from interviews along with photos were analyzed using the affinity diagramming process to help identify actionable areas of intervention (and spot outliers). The same was compared against the analysis of the photo interviews to create more inductive areas of intervention for AmI in everyday life.

The collected and analyzed data helped create a deeper understanding of certain events, behaviors, people, cultures and social forms. It helped to gain an understanding of users' needs for intervention and help gauge their level of comfort with new technologies (based on & combined with inferences from phase 1).

PHASE 2: Findings

Analysis of the data found that problems faced around the home space were almost always the same. The situation in which these inconveniences occurred may have changed across age and location. However, the core issue was common. Users shared the issue of drying utensils after running the dishwasher. A similar problem was seen in participants from India (where dishwashers are not a common household appliance) around the sink in the kitchen.

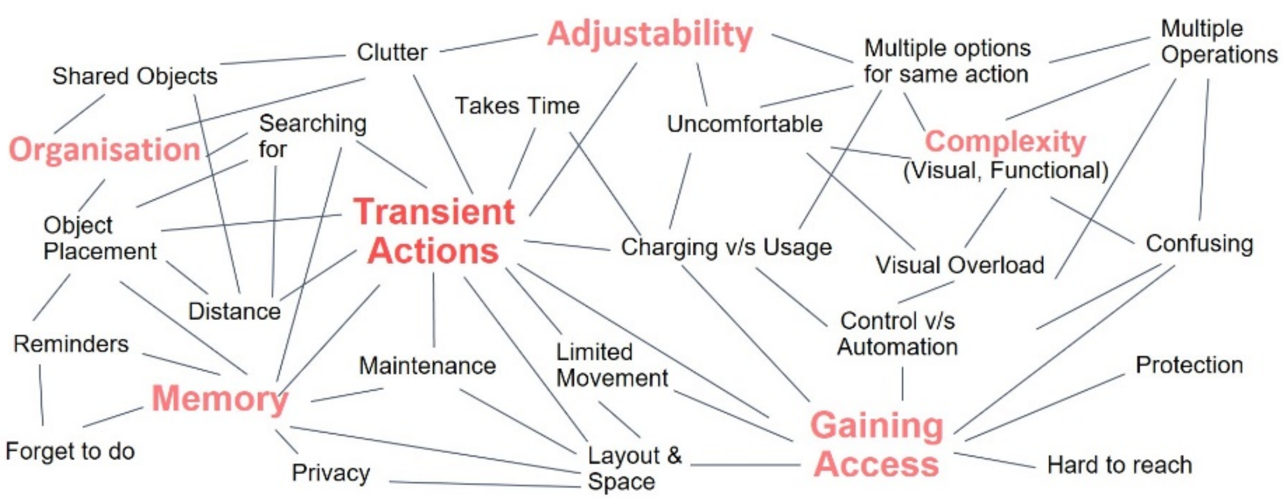

Figure 8: Areas of intervention from Phase 2

Mapping and clustering of the data collected through photo analysis and interviews showed that most inconveniences that participants shared were transient actions that were by themselves considered unimportant but were still necessary to accomplish a larger task. An example of this, is the task of using a mobile phone (to make calls) requires the transient actions of the device being charged, walking up to the device, picking it up and going back to where you were previously sitting.

Discussion with participants revealed that these “menial” activities were seen as a hindrance and there was a need for them to be bypassed in order to achieve an ultimate goal faster. Further, most participants did not mind the intervention of technology to make tasks easier provided that it helped reduce steps to a goal.

The mapped data further revealed that these menial activities can be broken down in to four major categories:

- Gaining/Blocking Access to…
- Remembering to do…
- Finding…
- Adjusting/Readjusting…

Results

The aim of this research was to collect data that investigates & proposes ideal dimensions of user interface & experience of wearable devices used, to operate within an ambient intelligence system, and its effect on user acceptability. The study further focused on gaining an understanding of possible areas in daily life where the use of AmI can help make experiences more meaningful. Thus, creating guidelines for the eventual development of wearable devices for consumers that help them use AmI systems more effectively, to improve the experience of daily activities, by making human needs the center of technology.

Results from the above experiments showed that there is a need for better interaction around the home space in order to help users achieve their daily goals by bypassing menial and unnecessary tasks. People are comfortable with the use of ambient intelligence to complete these tasks, provided that it does not visually affect their social image and the actions performed are simple, natural and familiar. Furthermore, the devices used to access these AmI systems must weave themselves into the environment and go unnoticed but at the same time are prominent enough to allow users to connect the action they are preforming to these tangible devices. This device must also provide an acceptable form of feedback that informs the user of the task in progress and its completion.

Limitations of Research

Trust, Acceptance & Control

Through the process of research, it was observed that while participants were fascinated by ambient technologies and were very interested in the idea of accessing technology without direct physical interaction, there was a lingering fear of "who is in control". Participants were not very keen on the idea of relinquishing control to a machine due to the fear that it may not always work as advertised. Furthermore, while the processes of machine learning can identify patterns and develop an understanding of user needs, it cannot yet account for irrational user behavior. Similarly, it cannot predict new behaviors and behaviors that are not routine. This is because the process of machine learning as Nikovic (2020) puts it, relies on messages (large amount of superficial data) rather than regulation (adaptive learning based on context). An example of this is the text prediction feature in mobile texting apps. AI's clear need for a learning curve for a device and proof that it may not always function properly led to a certain level of mistrust in AI technologies.

The Artificial Intelligence (AI) Dilemma

We live in a world where the established paradigm is that if humans can't (or won't) do it, technology will. This has become especially true with the introduction of AI and smart technologies. People start to believe that AI is and has the capability of becoming smarter than humans. While this is a possibility, given its current method of learning, we are very far from it. AI systems have a large working memory (Nikolic D. 2020) allowing them to handle complex calculations very well, which is some thing that humans can not do. Human learning, however, is different. It involves context and the understanding of deeper concepts rather than simply receiving input and instruction and producing output, which makes it a much more complex and deeper form of learning. This idea is further confirmed through Moravec's paradox, which states that we can teach machines to solve the hard problems, but it's the easy ones that are difficult (Hamer A. 2018). Boston Dynamics has developed a humanoid robot, Atlas, that can do back flips (Simon M. 2017). While this is a very impressive feat, what use is that if the machine does not know the context in which a backflip needs to be performed or why it should be performed at all. As a result of this, the belief that AI is the solution to everything is not true and will not be in any near future.

Feedback

Participants suggested that they while they did not mind relinquishing some control when it came to menial tasks, many mentioned that they would not consider this method of interaction for more important and private tasks. One of the reasons for this was a lack of understanding of weather the task had been performed accurately or not. The argument is that if a machine performs an action for a user, the feedback for the action (that the user would not need if he performed it himself) is lost and the user has no way of knowing if the interaction was performed or not. While the light exercise conducted in Phase 1 had a very clear feedback (Light turns on) other actions may not have as clear a feedback. Take the example of an automatic car lock, where the car senses the driver (car key) and knows to unlocks as the driver approaches and similarly locks as the driver walks away. The driver is not performing any clear action to lock or unlock the car and as such has no indication of whether the system is working or not.

Furthermore, there is no way of checking if the system is working as the car would automatically unlock as the driver approaches to check if the car is in fact locked. Most modern cars use blinking lights, as a form of feedback for this reason. However, flashing lights can sometimes go unnoticed. And as such the fear that the system hasn't worked properly can lead to mistrust in the technology.

Thesis Reframe

As a result of these limitations, the direction of the thesis was changed to focus less on the reliance on Artificial Intelligence as a solution to the problem and instead more focus was given to creating an intuitive ecosystem of interaction. Furthermore, the scope of the project was narrowed down to the spaces in and around the home spaces based on findings from Phase I.

Research Questions

How might we create a more intuitive/natural system of interaction using Wearable Technology more effectively in a home environment?

A. How might we create more ambiguity without effecting trust in functionality of AmI?

B. How might we create balance between Ambient & Physical interaction with the intermediate device in a way that is adopted faster?

The new direction takes the view of creating a system that acts as a master key to unlock technologies around the user with the user at the center of all interactions, without the use of technology making decisions for you. Rather technology is used as an enabler that allows you to access the AI of the already existing array of smart devices in your home.

Actions, States & Indicators

In interaction design, any interaction with a product, weather it is physical or digital, there are 3 major steps. There is an action that is performed, a state that is changed and an indicator of the state being changed. For example, in order to open a door, an action of turning a key is performed. This in turn causes the system to change from locked to unlocked state. As a result of this, the door opens which is an indicator that the door has opened. This a fairly simple way of explaining these 3 steps but in reality, the interaction is much more complex. There are multiple actions involved in opening a door. A key is inserted into the lock, it is turned, the knob is turned, and the door is then pushed. Each of these actions has a change in state that follows it and there is a subsequent indicator too. However, in everyday life, we tend to skip these menial steps while explaining the process, even though we perform them.

Human Interface (HI) Approach

The human interface approach builds on the idea of skipping menial micro-actions and takes it a step further. It clubs together actions performed, into one unnoticeable action, thus hiding the menial micro-actions from the user. In essence all the actions are still being performed. However, they go unnoticed by the user.

Take the example of unlocking the door to enter the room. A key is used in order to stop other people from entering. In other words, the key acts as an identifier that the specific user is allowed to enter. If this identifier was converted to a digital signal on a wearable device, that could be sensed by the door, the action of entering the key into the keyhole and turning it is unnecessary. A similar action is still being performed; however, the user is unaware of it. As a result of this all the micro-actions could be hidden into the larger and obvious action of turning the doorknob to open it, which is something that the user must do anyway to enter. The action can be taken even a step further so that when the knob is touched, the door unlocks, the thermostat is set to 73ºF and the passage lights turn on for 10 minutes.

For this system to work, there are four major factors that need to be considered: a connected AmI ecosystem, an intermediate device, feedback & manual overrides. Introducing an Intermediate device that eliminates menial action by reading natural gestures (Ex touching doorknob) allows the user to control multiple actions without the need of advanced sensing methods or a high level of machine learning. As this system uses user presence and actions as a driver for interaction with the space around him, it makes sense that the device should always be on the user. Thus, a wearable device is ideal for this situation. This wearable is in essence a cluster of various sensors that allow the AmI environment to read human presence and actions.

The second challenge for this approach is to create trust in the system. Providing feedback that is noticeable & clearly informs the user of a change in state, becomes very important for this system. There should also be a provision for manual override to change states to give the user to set and reset states that change. These factors help create more ambiguity for the system while keeping the trust of the user intact.

Moving Away from Complete AI Decisions

The major difference between AI and HI is that the actions performed are user centric rather than being machine centric. The H.I. approach still uses A.I., however, it is used as an enabler of smart technology rather than a being used as a decision maker through the process of machine learning. As a result of this, there is no learning curve involved for the system to understand user behavior.

Take the nest thermostat that uses AI and machine learning to learn user habits. Over time it learns that a user prefers the room temperature to be at 750F in the evenings and automatically sets the temperature at around 5:00pm. While this is very desirable in some cases, it fails in others. Say the thermostat is installed in your holiday home that you visit once every 2 months. Based on past behaviors it will run up your electricity bill as it will assume that you want the temperature to be set to 75^{O}F every evening even though you use it for 5 days in a month. With the HI Approach however, the temperature is set as you enter the house and as such it activates based on human presence and actions (In this case opening the door).

With the HI approach, all actions are still controlled by the user and not by the AI. This is how it differentiates itself from most existing smart technology. The system performs discrete actions that change a state from on to off or open to close. The main purpose of this system is not to perform functions in an AmI space, but rather to activate functions on other smart devices, thus leveraging their already existing and proficient AI to interact better with the user.

The AmI Ecosystem

For this concept to work, there also needs to be an ecosystem of smart devices that can communicate with each other. As a result of this, existing smart home systems were looked at as a starting point, in order identify how devices communicate within a network.

Interestingly, it was observed that the smart devices in fact do not communicate very well with each other. They have the technology to communicate with each other either over Wi-fi or via NFC/RFID sensors. However, due to differences in brand and separate parent apps, their communication is only limited to their specific ecosystems.

The exception to this is the recently emerged market of smart speakers. These devices act as a control for smart devices around the home and make human voice the primary input to control the smart home. While this method of interaction does have a higher level of ambiguity than screens, they still require the user to enter the interface of the device and need specific commands to perform functions. There is still a clear input required for the system to work and as seen in Phase 1, participants have a desire to stare at a tangible object to root the interaction in a physical space thus leading to the system not being truly ambiguous.

Further, when it comes to audio language inputs, there are many factors to consider. Tone, pitch, phrasing & accents play a big role in the development of voice input. Failure to recognize and process user input can lead to frustration. In fact, one of the most common complaints with smart speakers is that the device does not understand user input.

While there are a few issues with voice input, these smart speakers however, come closest to creating a unified ecosystem of smart products. As a result of this, the google home network and Alexa skills were observed as reference smart home systems for this thesis.

Phase 3: *Observations + Survey*

Phase 3 focused on collecting information about how participants interact with smart speakers to control the smart devices in their home. The goal was to get an understanding of the pains and gains of existing smart home systems and identify the possibility of an alternate system of connectivity and interaction that could be implemented for this thesis project.

Observations were used as a data collection method. Participants were observed while interacting with their smart homes using a smart speaker to control their home. They were shadowed while they went through their morning routine before they went to work and their evening routine after coming back from work. Further, as another goal of this exercise was to capture user routines, a weekday was selected for the shadowing exercise as participants had a fixed schedule compared to the weekends.

The type of data collected focused on number of tries to activate a specific device and the effect of increasing complexity of voice input commands on system function, and level of user frustration (Likert scale) with the system in case of failure. Participants were also asked to fill out a short survey to voice these complaints. Additionally, participants were also asked to specify what smart devices they already owned and devices they would like to own in the future in order to gauge their interest in the idea of a connected smart home system. Data collected was visually quantified using graphs and charts to help identify emergent patterns in behavior that can address possible issues faced in this thesis.

Figure 9: Participant frustration with voice assistants

Phase 3: *Initial Findings*

Apart from confirming findings from secondary research about issues with audio input for smart speaker systems, Phase 3 also shed light on the fact that while these systems work very hard to create an inclusive device ecosystem, all smart devices do not work on all systems. While 92% of the participants were interested in building a connected smart device ecosystem, a common fear for participants was whether the device would work with and integrate into their currently owned smart speaker ecosystem.

Further, it was observed that while these smart speakers connect third party smart devices to their ecosystem, these devises are isolated from other devices within the system. As a result, the system works well when the user wants to use a specific smart device. However, it does not allow sharing and communicating of devices within the system to create an interconnected web of information.

User Experience maps

Observations from phase 3, along with findings from phase 2 were used to develop experience maps to visually depict what the user is doing, thinking and feeling as they go through the journey of their daily routines. As this thesis is focused on the home environment, other journeys outside it were not considered. It should be noted at this point that these experience maps are not specific to one user and are developed using insights from multiple user observations to create a common experience flow. The existing experience mood is then juxtaposed against a future experience that this thesis concept will achieve to alleviate pain points observed.

The home experience journey for weekdays can be broken into two major parts based on time of day. These are the morning and evening routines that the participants go through to start and end the day. These larger routines consist of set actions or tasks that the user completes in a specific sequence. Each of these actions can be further broken down into smaller steps that are done in order to complete the task. Considering that findings from phase 2 stated that menial tasks were seen as a hinderance, these experience maps attempt to go into as much detail as possible in order to further isolate menial tasks that negatively affect user feelings and identify root causes that effect user mood.

The morning routine includes the broad actions of waking up, making breakfast, bathing and grooming, packing for work and leaving. At first glance, it is noticeable that the overall mood in the mornings is not good. Specifically waking up and getting out of bed is not a pleasant experience. This is an effect of a sudden change activity. It is observed that sudden shocks disrupt the natural flow of actions and lead to a decline in user mood. An example of this is an alarm that disrupts the natural flow of waking up. However, given that users have set schedules for their day, it is necessary to wake up at a specific time. Data from phase 3 suggests that users is not truly awake until they reach and complete the bathing task in the morning routine and the process of waking up takes time.

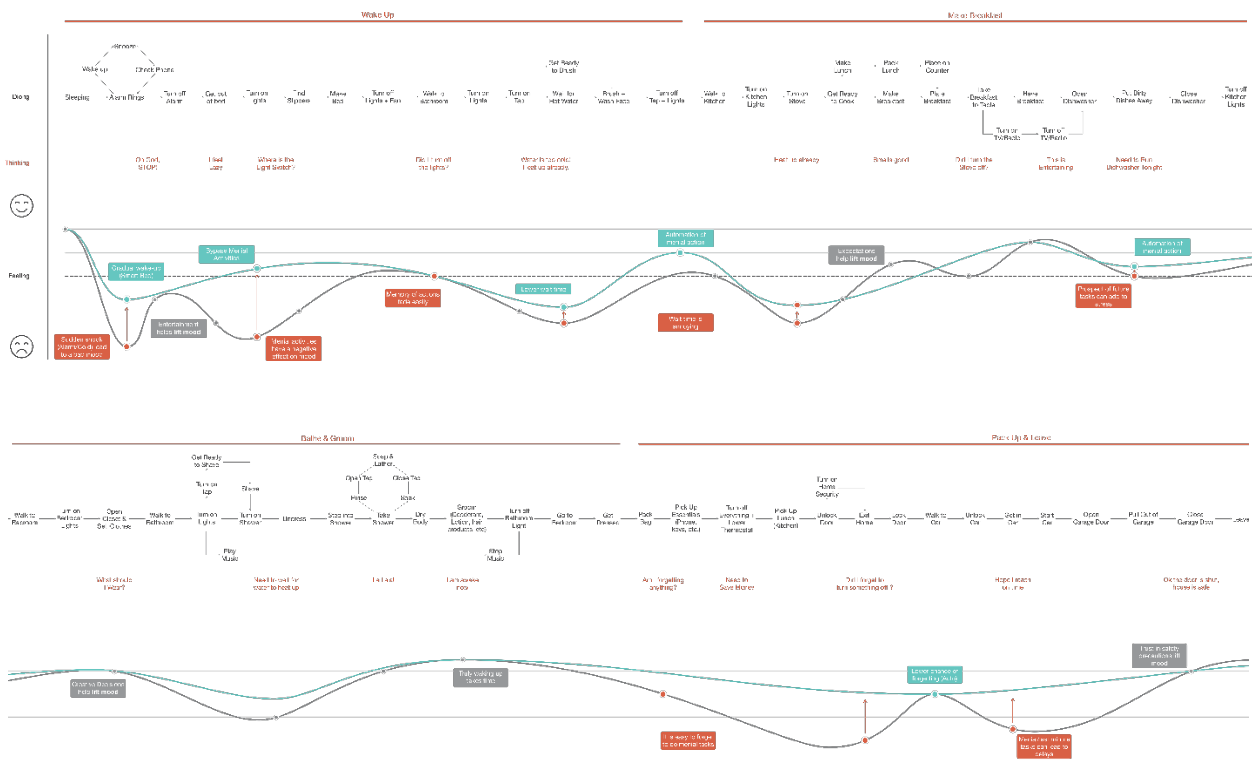

Figure 10: Experience Map 1 (Morning routine)

The task of waking up is a tedious process and users have different methods and devices used for coping with it. Gentle wake up alarm clocks control intensity of alarm sound in order to help gradually wake the user. A quick market search for alarm clocks showed that there are also alarm clocks that use light and nature sounds to simulate a sunrise to help alleviate stress that is accompanied with jarring alarm clocks (Adelson, K.I., 2018). However, these devices usually only activate one or more of the user's senses and can fail. When probed for more information, a participant shared that to help him wake up, he would set his smart thermostat to high when his alarm rings in order to help him wake up. Others mention that in situations where they have to wake up at a specific time, they purposely use jarring methods like turning on the lights at full brightness. They do not like this experience but unfortunately, they believe that there is no better way. There is an opportunity here to use a connected smart device system that triggers multiple devices like lights, heating, and speakers to create an alarm that triggers all the user's senses and provides a more gradual and natural wake up routine.

Further, as discussed in phase 2, the experience map shows that menial tasks negatively affect user mood. An example of this is fumbling to find a light switch in the dark. Furthermore, while activating the menial task is a matter of repetitive practice that is driven by need (to complete the larger task), in many cases users forget to reset the device to its default state once the task is over. As these tasks are menial, it is a common occurrence that the memory of the menial task fades easily and users tend to forget about it as they are focusing on completing the larger task. This especially holds true when the user is rushed to complete tasks when they are running short on time. An example of this is the last-minute check to make sure that all the devices in the home are off before the user leaves for work to save on the electric bill. In this situation, apart from accessing memory to make sure that all devices are accounted for, the user also has to manage time to make sure that they are not running late. As a result of this, it is a common fear among users to feel like they missed something and this in turn may lead to stress. Similarly, the prospect of future tasks that need to be performed also require the user to store information in their memory. This can also add to user stress. There is an opportunity here to use automation of menial tasks to alleviate some of this stress by using an HI centered connected device ecosystem to reduce reliance on memory. Again, as mentioned earlier in this situation keeping user trust in the system intact becomes very important and this is done by providing clear feedback and allowing for manual checks and feedback.

Another common cause of user annoyance is the need to wait for certain devices to change to their desired state. An example of this is waiting for the water to get hot while in the shower. Some users have adapted their routines to compensate for these wait times by performing other tasks while the state is changing. However, this is not always possible. The use of a connected device system allows these devices with long wait times to prepare before the user arrives to use them thus reducing these wait times and improving user mood.

Finally, it was observed that expectations of positive experiences help lift mood. These experiences include food, entertainment, refreshment and creative decision making. Further, the successful completion of a task has a similar effect.

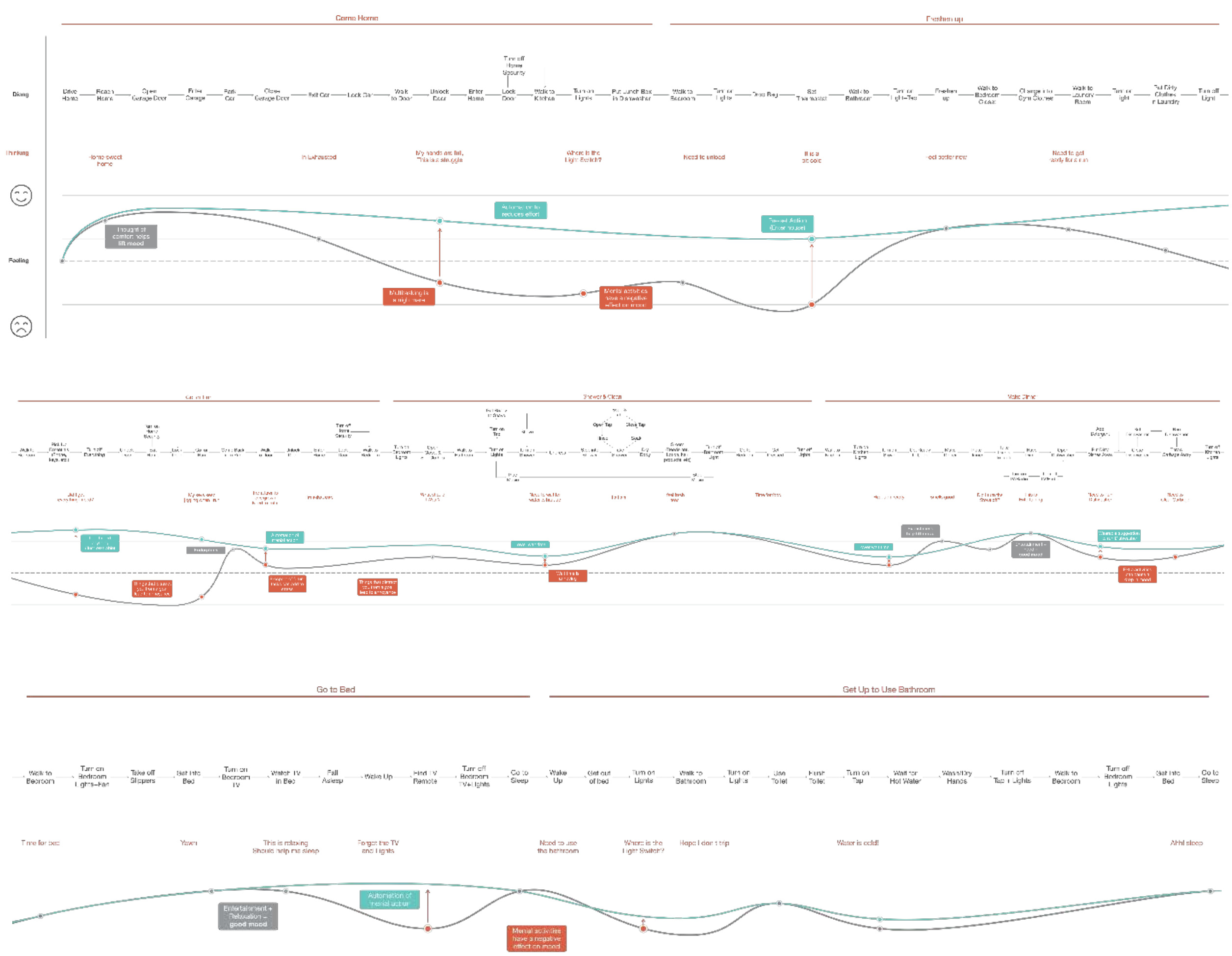

Figure 11: Experience Map 2 (Evening routine)

While in the morning routine, most of the tasks are focused on waking up and getting ready, the evening routine focuses on unwinding and relaxing. As a result, the overall experience is less negative than the morning routine. The evening routine consists the broad tasks of coming home, freshening up, exercise, making dinner and going to bed. The thought of comfort and relaxation helps improve user mood. However, as seen in the morning routine, menial tasks and wait times are still a hinderance, especially when multitasking is involved.

Apart from these pain points, any action that distracts from achieving a goal also affects user mood. An example of this is the need to carry essentials like keys and a phone while going for a run. The use of a connected HI device system that uses a wearable to access the system helps solve these issues as in leads to a scenario where the user does not need to carry as many essentials. Finally, as observed in the morning routine, expectations of positive experiences and successful completion of tasks within the evening routine help lift mood.

Current/Future Situation

Now that an understanding of the existing experience and possible areas of intervention have been established, it becomes imperative to identify how the proposed solution will addresses these pain points. As the proposed solution still relies on leveraging existing smart device functions, there is a need to analyze device specific interactions within current smart systems and identify possible alternate interactions for the proposed solution.

The list of desired smart devices from the phase 3 survey and their interactions were tabulated to include activities performed, input methods used, when the activity was being used and what the goal of the activity was; to develop an understanding of how, when & why these devices were used on a daily basis. This process helped identify possible Human Interface (HI) actions that could be used to replace traditional input methods (screen/audio) used in current systems.

	Device	Type / Location	Activity (States)	Current Action	Current Action (secondary)	When (Action Performed)	Why (Action Performed)	Invisable Action (Wearable)	Decision v/s Suggestion	Technology (Sensors / Data)
1	Smart Speaker	Rooms	Ask questions	Voice command	x	As needed	Access Information	x	x	x
			Control devices	Voice command	x	As needed	Automation	x	x	x
			Play audio	Voice command	x	As needed (in Proximity)	Entertainment	x	x	x
			Set Volume	Voice command	x	Too Loud/Soft	Preferance	Wearable	Manual Input	Manual Input
2	Smart TV	Living Room, Den, Bedrooms	Turn ON	Remote	Voice command	Sitting in room, Expecting show at specific time	Entertainment	Sit infront of TV	Suggestion	Proximity
			Find Media	Remote	Voice command	After Device is Turned On	Interest Driven	x	x	x
			Pause/Play Media	Remote	Voice command	Distraction Occurred	Distraction Occurred	Walk Away	Suggestion (Setting)	Proximity
			Set Volume	Remote	Voice command	Too Loud/Soft	Preferance	Wearable	Manual Input	Manual Input
3	Smart Outlet	Each Room	Turn ON	Voice command	x	Use Attatched Divice	Device Specific	Enter Room (Device/Schedule based)	Suggestion	Proximity
			Turn OFF	Voice command	x	Done Using Device	Device Specific	Other Devices Information	Suggestion	Proximity
4	Thermostat	Passage, Living Room	Change Temperature	Device control	Voice command	Enter/exit home, Sudden drop in temp	Discomfert	Enter/Exit Home, In (Smart) Bed	Decision	Proximity+External Data
			Change Mode	Device control	Voice command	Change of seasons	Save Energy	Change of seasons	Decision	External Data
			Set Schedules	Device control	Smart Phone App	Based on time spent at home	Save Energy	x	x	x
			Settings	Device control	Smart Phone App	Only when needed	Discomfort, Save Money	x	x	x
5	Lights	Rooms, Accent	Turn ON	Smart Phone App	Voice command	Enter Room	Find, See	Enter Room	Decision	Proximity
			Turn OFF	Smart Phone App	Voice command	Exit Room	Save Energy	Exit Room	Decision	Proximity
			Intensity	Smart Phone App	Voice command	Time of day, mood	Discomfort	Wearable	Manual Input	Manual Input
		Desk, Night Lamp	Turn ON	Smart Phone App	Voice command	Sit at Desk	Find, See	Sit at Desk	Decision	Proximity
			Turn OFF	Smart Phone App	Voice command	Leave Desk	Save Energy	Leave Desk	Decision	Proximity
			Intensity	Smart Phone App	Voice command	Time of day, mood	Discomfort	Wearable	Manual Input	Manual Input
6	Fan	Rooms	Turn ON	Smart Phone App	Voice command	Enter Room	Discomfort	Enter Room	Suggestion	Proximity
			Turn OFF	Smart Phone App	Voice command	Exit Room	Save Energy	Exit Room	Suggestion	Proximity
7	Window Blinds	Rooms	Open	Smart Phone App	Voice command	Time of day, mood	Find, See	Time of day, mood (In Room)	Decision	Proximity
			Close	Smart Phone App	Voice command	Time of day, mood	Save Energy	Time of day, mood (In Room)	Decision	Proximity
			Intensity	Smart Phone App	Voice command	Time of day, mood	Discomfort	Time of day, mood (In Room)	Decision	External Data
8	Shower & Taps	Bathrooms, Kitchen	Turn ON	Digital control / Motion Sense	Voice command	Using Water	Wash Up	x	x	x
			Turn OFF	Digital control / Motion Sense	Voice command	Finished Using Water	Save Water	x	x	x
			Set Temperature	Digital control	Voice command	Weather, Time of Day	Discomfort	x	x	x
9	Bed (Primary Mode)	Bedroom	Angle	Sensors	x	Snoring	Reduce Snoring	x	x	x
			Firmness	Sensors	x	Tossing & Turning	Sleep Quality	x	x	x
			Track Sleep	Sensors	x	Sleeping	Sleep Quality	x	x	x
10	Door Locks	Home Entry	Unlock	Key	Keypad/Fob	Want to Go Through	Safety	Touch Door Handle	Decision	Contact
			Lock	Key	Keypad/Fob	Passed Through	Safety	Release Door Handle	Decision	Contact
11	Security Cameras	Entryways, Inside Home, Yard	Turn ON	Smart Phone App	x	Leaving Home, Sleeping	Safety	Leave home, Get in bed	Decision	Proximity
			Turn OFF	Smart Phone App	x	Entering home	Save Energy	Come Home	Decision (Setting)	Proximity
			Check Recording	Smart Phone App	x	Fear of B&E	Safety	x	x	x
			Save Recording	Smart Phone App	x	Fear of B&E	Safety	x	x	x
12	Car Lock	Garage	Unlock	Key	Contact	Enter/Exit Car	Enter/Exit Car	Touch Door Handle	Decision	Contact
			Lock	Key	Contact	In/Away from Car	Safety	Release Door Handle	Decision	Contact
13	Garage Door	Garage	Open	Remote	x	Leaving/Entering Garage	Leave Home	Turn Car On/Reach Garage	Decision	Proximity+External Data
			Close	Remote	Time Delay	In/Out of Garage	Safety	Leave Garage/Turn Car Off	Decision	Proximity+External Data
14	Dustbin	Kitchen	Open	Motion Sensor	Manual Control	Throw Away	Hygene	x	x	x
			Close	Time Delay	Manual Control	Finished Throwing Away	Hygene	x	x	x
15	Vaccum	Rooms	Clean	Automatic	Smart Phone App	when away from home (Schedule)	Clean Dirt & Spills	Leave home	Decision (Setting)	Proximity
			Charge	Automatic	x	Automatic	x	x	x	x
			Set Schedules	Smart Phone App	x	Installtion	Avoid disturbing its path	x	x	x
16	Lawn Mower	Yard/Lawn	Cut	Automatic	Smart Phone App	when away from home (Schedule)	Maintain Lawn	Leave home	Decision (Setting)	Proximity
			Charge	Automatic	x	Automatic	x	x	x	x
			Set Schedules	Smart Phone App	x	Installtion	Avoid disturbing its path	x	x	x
17	Sprinkler	Yard/Lawn	Turn ON	Automatic	Smart Phone App	when away from home (Schedule)	Maintain Lawn	Leave home	Decision (Setting)	Proximity
			Turn OFF	Automatic	x	Automatic	Gets in the way	Come Home	Decision	External Data
			Set Schedules	Smart Phone App	x	Installtion	Avoid disturbing its path	x	x	x
18	Pool Cleaner	Pool	Turn ON	Automatic	Smart Phone App	Away from Home (Schedule)	Maintain Pool	Leave home	Decision (Setting)	Proximity
			Turn OFF	Smart Phone App	x	Winter Season	Pool Covered	Change of seasons	Decision	External Data
			Set Schedules	Smart Phone App	x	Installtion	Avoid disturbing its path	x	x	x
19	Grill	Yard/Lawn	Start Cooking	Device Control	Smart Phone App	Hungry/Routine	Cook/Heat Food	Entering Home	Suggestion (Setting)	Proximity
			Set Time	Device Control	Smart Phone App	When Necessary	Proper Cooking	x	x	x
			Turn OFF	Device Control	Smart Phone App	Done Cooking	Safety	Leave Home/Done Cooking	Decision (Setting)	Proximity
20	Stove/Oven	Kitchen	Start Cooking (Preheat)	Device Control	Voice command	Hungry/Routine	Cook/Heat Food	Entering Home	Suggestion (Setting)	Proximity
			Set Time	Device Control	Voice command	When Necessary	Proper Cooking	x	x	x
			Turn OFF	Device Control	Voice command	Done Cooking	Safety	Leave Home/Done Cooking	Decision (Setting)	Proximity
21	Microwave	Kitchen	Start Cooking	Device Control	Voice command	Hungry/Routine	Cook/Heat Food	x	x	x
			Set Time	Device Control	Voice command	When Necessary	Proper Cooking	x	x	x
			Turn OFF	Device Control	Voice command	Done Cooking	Safety	Leave Home	Decision	Proximity
22	Fridge	Kitchen	Look up Recipies	Device Control	Smart Phone App	Trying Something New	Assistance with cooking	x	x	x
			Expiry Dates	Device Control	Smart Phone App	Forgotten Foods	Avoid Food Going Bad	x	x	x
			Grocery Lists	Device Control	Smart Phone App	Out of Regular Items	Never Run Out of Essentials	x	x	x
			Custom Temperatures	Device Control	Smart Phone App	Special Storage Requirements	Maintain Food Better	x	x	x
23	Dishwasher	Kitchen	Turn ON	Device Control	Smart Phone App	Machine Full/Routine	Wash Clothes	Choose Preset Mode/When Full	Suggestion (Setting)	Proximity+External Data
			Turn OFF	Device Control	Smart Phone App	Run Issue	Run Issue	Wearable	Manual Input	Manual Input
24	Washer/Dryer	Laundry Room	Turn ON	Device Control	Smart Phone App	Machine Full/Routine	Wash Dishes	Choose Preset Mode/When Full	Suggestion (Setting)	Proximity+External Data
			Turn OFF	Device Control	Smart Phone App	Run Issue	Run Issue	Wearable	x	Manual Input

Figure 12: Device, Activity, Action Table

Decision v/s Suggestion

As seen in the limitations of research, there was a lingering fear of "who is in control". Participants were not very keen on the idea of relinquishing control to a machine due to the fear that it may not always work as advertised. The tabulated data further proved this point and helped identify that all HI activated actions cannot always be decisions. This became especially true in the case of actions where user safety is a concern. It is dangerous for devices like smart stoves to turn on by themselves without deliberate action input. As a result of this, it became necessary that certain HI actions be suggestions that the user can chose to activate, instead of being automated decisions. Automated decisions on the other hand, work well as a failsafe for these higher risk devices. With the smart stove for example, it will turn off automatically if the user leaves the home. It was further identified that actions can be grouped into three categories: home, away and asleep; and devices can be grouped into either active or inactive state.

Finally, as mentioned earlier in the introduction of the HI approach, there is also need for manual control & override of HI actions to account for irrational human behaviors that do not follow predefined routines to keep trust in system function intact.

Controls, Capabilities and Technologies

Apart from identifying functions of the wearable device, the tabulated data also helped gain an initial idea of the input modality & controls that would be required to interact with the ecosystem. Understanding the reason and time of why an action was performed further helped identify the technology and types of sensors that would be needed in order to perform these HI actions. This further helped differentiate this concept from existing smart home systems.

The WT device will need to be capable of sensing proximity, contact, body readings (pulse, pressure, breath, etc.) and external data relating to time, location, and smart device states. Apart from this, the device must also provide affordance for manual input and override of smart device states in the case that the system makes an undesirable decision. Most smart systems today use home Wi-Fi to share information between the device and the smart ecosystem. This also proves to be an effective source of external data for system function. This technology can be used for this concept in the same way. Furthermore, most smart watches can sense body readings using an array of sensors that can fit in a small form factor and can be used for the WT device being developed for this thesis. When it comes to proximity and contact sensing however, thought needs to be put in to decide what technology will be used. In order to achieve these sensing qualities, the device can either use NFC/RFID beacons that use radio waves to uniquely identify items and send information between devices, or a local geolocation system that creates a local net in which items can be tracked (similar to GPS systems).

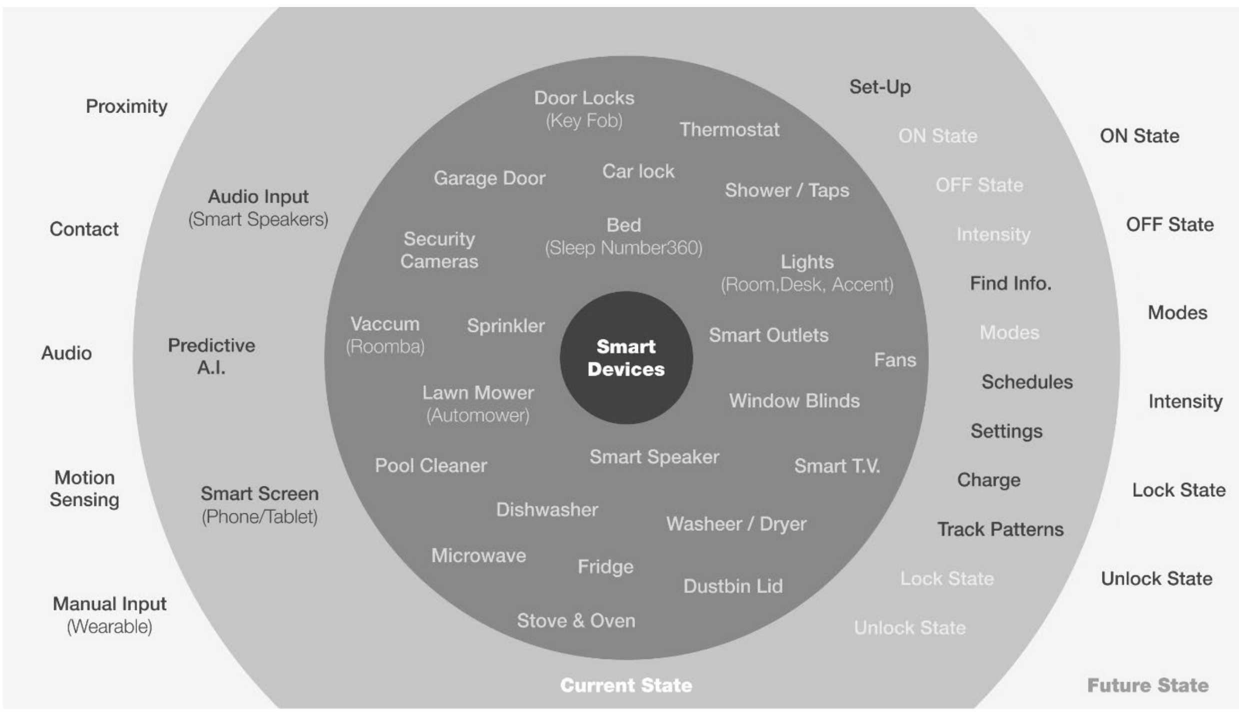

Figure 13: Control - Capabilities Map

While the geo location method does provide better connectivity between devices and further help map physical spaces based on location rather than user input, the main problem faced is the need to set up infrastructure that allows for the net to be cast around the home. Further, there are limitations to system function outside the net of coverage. RFID tags on the other hand are smaller, cheaper and require less power and external data input to function which makes them a better choice for this thesis. For this project focus is given to NFC technology which is a subset of RFID that is designed to be a secure form of data exchange. Further, an NFC device is capable of being both an NFC reader and an NFC tag (Thrasher, J. 2013). Which helps reduce complexity of components within the system. NFC technology does not give any information of physical location. It can however be used to digitally locate the user as and when it is picked up by a device in a specific room. Furthermore, NFC tags can also be used to demarcate larger physical spaces. For example, an NFC tag that is stuck to the door leading to the living room activates specific devices in that room as the user walks past it.

Limitations of WT in AmI Spaces

Central Command

While conducting data collection for phase 3, it was also observed that apart from device interactions for daily use that are usually discrete actions, there is also a need to perform more complex interactions that are required to set up smart devices within the ecosystem, edit device and ecosystem settings and specify when and how the HI actions will be activated. Further, there must also be a provision for a backup system that can be used in case there is a failure with the wearable (Ex. If the wearable battery is drained).

These more complex functions still require a traditional screen and input modality in order to initially set up the ecosystem and actions within it. However, as mentioned in the literature, smart wearables are physically much smaller (1/5th size of smartphones), and its wearability must be considered for various situations of on-device interaction. Given the smaller screen real estate on a wearable device, performing these more complex actions with traditional UI becomes very hard. There is therefore a need for an assistant device with a traditional screen UI to perform these actions.

In essence, there is need for a central command or hub device that can assist with the initial set up and modifying preferences later on. A central command can also help the ecosystem access external data for the ecosystem thus allowing the wearable to leverage mobile technologies to overcome shortcomings in wearable sensing and further reduce wearable size and complexity. There are two possible solutions for this. Either, a dedicated hub device can be introduced into the ecosystem that acts as a central command (like in the case of most smart home systems today), or the user's mobile Phone can be used as a central hub to access this information.

While a dedicated hub device has the benefit of being a central tangible device that brings the whole system together and can be accessed by anyone inside the house, the mobile phone app allows for more flexibility in use. A mobile app can provide specific and limited access to multiple users (who each have the app on their personal device) who interact with the AmI space in their own specific way. Further, an app allows users to take the central command with them wherever they go, making it a useful backup device in case of wearable failure. Finally, adding a dedicated hub device to the ecosystem would add to purchase & installation costs to set up the system. Based on these factors, a phone app is more effective as a central command due to its versatility.

Power Consumption & Charging of WT Devices

While determining wearable device functions and input modalities, it was further identified that a device of this kind would require to be charged from time to time. Considering how this ecosystem works, the device needs to always be on the user for them to interact with the space around them. This led to the challenge of making the system work smoothly when the device is not on the user and is charging.

To understand charging behaviors of users, a quick google search was conducted with the search input of “charging phone”. This led to a plethora of articles, most of which mentioned overnight device charging. An article from PCMAG.com (Griffith E., 2019) further goes on to mention that many myths around charging your phone overnight are in fact untrue. Given the frequency of the phrase “overnight charging” when talking about phone charging, it is safe to assume that charging devices overnight is a common practice among users.

As mentioned earlier, device actions can be categorized in three major categories, one of which is ‘asleep’. Further, as observed in the tabulated data from phase 3, very few devices are active when the user is asleep and even fewer ones require a change in state. As a result of this, it is possible to use the action of charging the wearable as a control to activate ‘sleep mode’ which is a preset mode that sets and locks states of specific smart devices within the home until the wearable is back on the user’s body.

Device Networks & Ecosystem

As mentioned in the phase 3 initial findings, existing smart systems do not allow sharing and communicating of devices within the system to create an interconnected web of information. However, we can see from the experience maps that a connected ecosystem has many positive attributes that can help address user pain-points. As a next step, the list of smart devices from the phase 3 survey were mapped to identify relationships between each other and see which devices depended on information from other devices to create a connected ecosystem of devices that actually communicate with each other. Firstly, it was observed that, as in any smart system, the more devices there are within that ecosystem, the more robust it becomes and the better it functions

Further, it was observed that some devices have the potential of being used as HI control activators. An example of this is current smart beds in the market. For this thesis, the Sleep

Number 360 smart bed is taken into consideration. This smart bed senses the user's sleep patterns and movements to provide information about quality of sleep. In a connected smart device ecosystem, this data can be further used during sleep mode to control other smart devices. For example, if the user gets out of bed in the middle of the night to use the rest room, the resulting data from the smart bed could be used to turn on the passage lights at a specific intensity and set the smart tap water to a certain temperature. Similarly, if the bed senses that the user uncomfortable while in bed, it can activate the smart speaker to play nature sounds and help the user relax.

At this stage it should be taken into consideration that not every user that buys into this ecosystem will have a smart bed in which case, the sleep mode is a predefined and locked set of states for specific devices. But as mentioned earlier, the more devices there are within the ecosystem, the better it functions. The smart phone (app), smart speakers, wearable device, smart bed and smart car can act as nodes to create a more robust system of communication within this ecosystem.

On the other hand, research into the list of smart devices and their functions revealed that some smart devices rely completely on Wi-Fi and have no NFC or any RFID capability. In this situation, there is need for a separate NFC tag that needs to be added to the device so that it can be recognized by the WT device. As NFC tags are useful for these devices and can also be used demarcate physical spaces, they should be provided in the box when buying into this system. Given that NFC tags are relatively inexpensive, they should not affect cost of the product and system.

Intermediate WT Device Considerations

As mentioned in the introduction to the HI approach, there is need for an intermediate wearable device that not only acts as an identifier to represent the user in this ambient ecosystem, but also provides the user with adequate feedback of changing states.

Phase 4: Form & Placement Considerations

As humans use their arms & hands for most actions that they perform, this part of the body becomes an ideal location for the placement of the wearable. Furthermore, visual or tactile feedback can be provided to a device placed here as it will be more noticeable.

To collect more information about user preference on device placement, Participants from previous research were shown images of various devices that would connect them to a smart environment around them. For each device, they were asked to answer questions that gauge preference, time of contact, fashion worthiness, noticeability and tangibility. Data collected was analyzed to create a ranking of preferred devices that suit function.

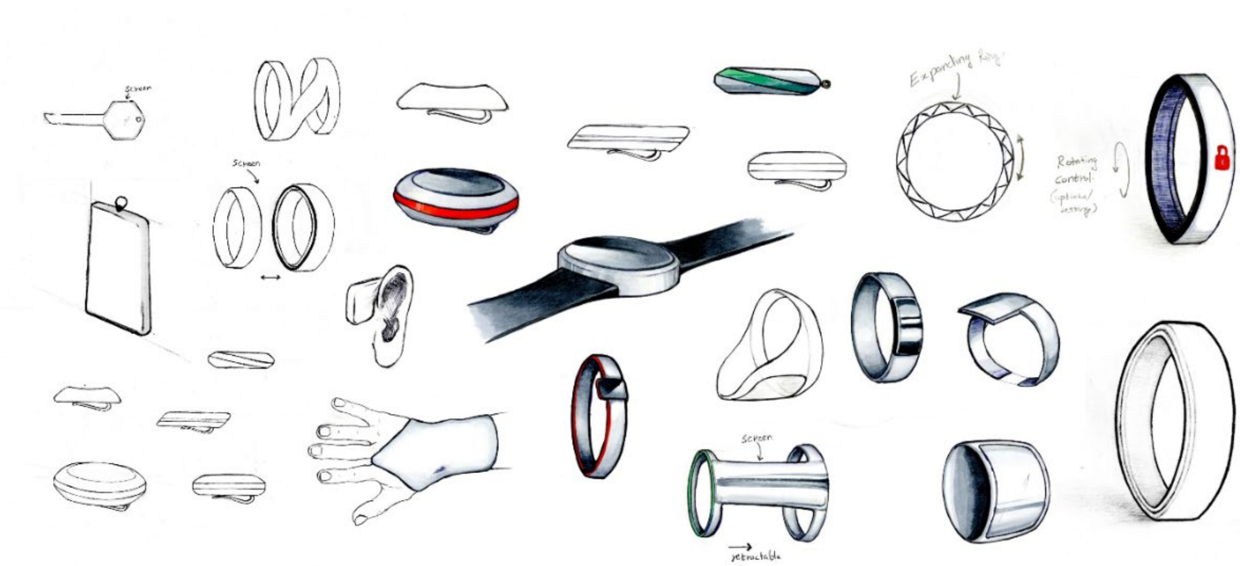

Figure 14: Reference Images used for Phase 4 exercise

Phase 4: Findings

Based on participant feedback, it was observed that a watch/wrist band, Ring and implant/sticker were the top 3 preferred devices. It was further observed that while all 3 devices had pros and cons, no one device could be called an ideal device due to the varied preferences of different users. A participant mentioned that, "what I like is very different from what my husband likes. I prefer things that are subtle and hidden away while he prefers things that are bold and show that he is tech-savvy".

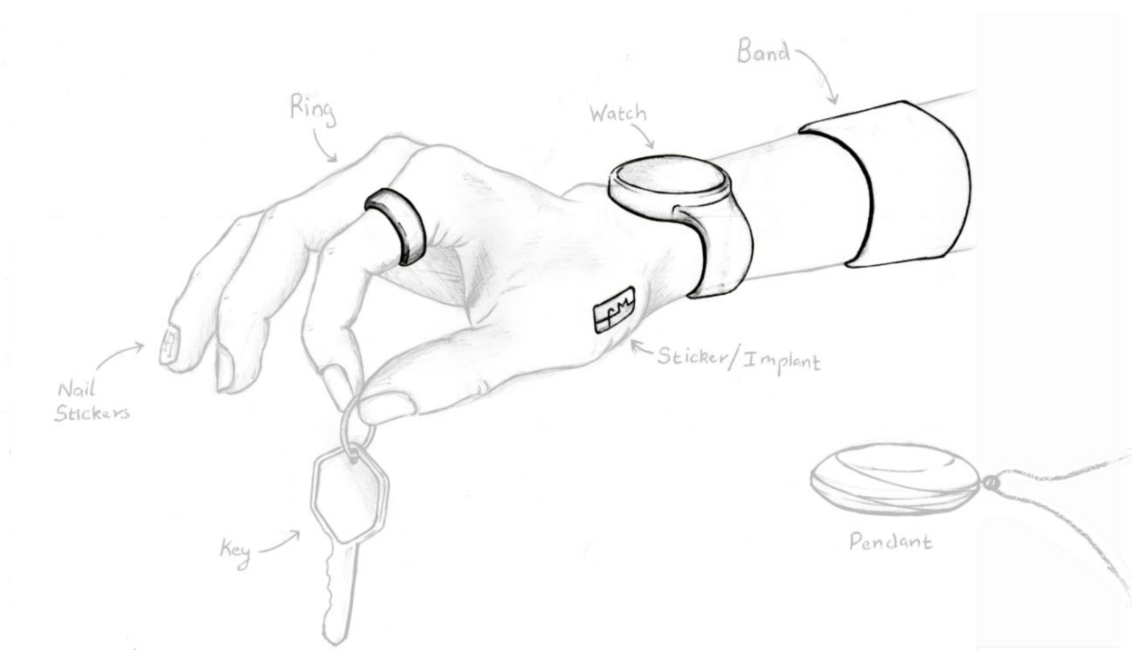

Figure 15: Proposed wearable forms

Furthermore, the choice of device was heavily influenced the wearable devices the user already owned. In many instances, while participants preferred the watch form, they were unwilling to buy a separate watch for just a single purpose as they already owned a smart watch. This led to the inference that instead of sticking to one form that force fits the form requirement for all participants, there is potential for the creation of a range of device forms that range from to inconspicuous to bold and basic to highly functional.

Form Ideation

Ideation and exploration exercises were conducted to develop WT devices that would fit criteria set by findings from phase 1,2, 3 and 4. These ideations explored device form for the selected placement directions and control interactions with these forms. As observed in the literature review and phase 1, hedonic qualities of WT are likely to play an influential role in technology adoption. If users expect to experience these devices in similar ways as their clothes and accessories, it makes sense that the design of WT must take inspiration from and pay homage to fashion, form and interactions that are predominant among accessories available today.

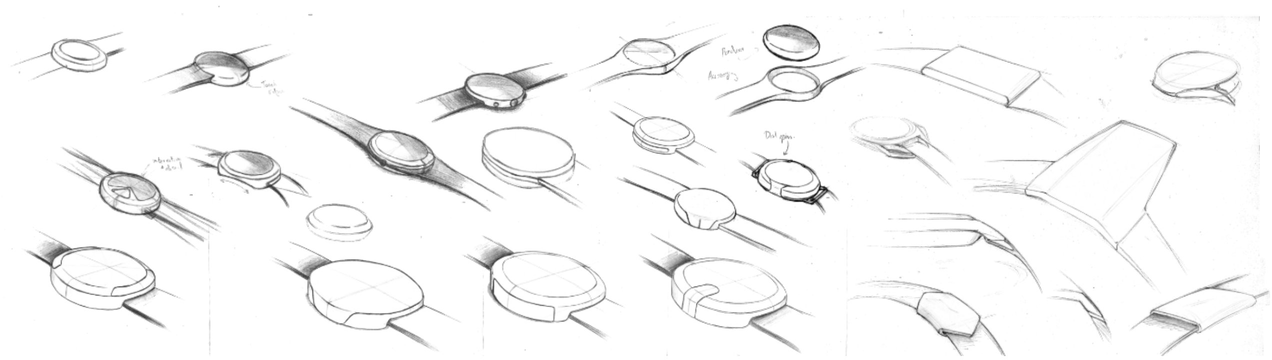

Figure 16: Form & Control Exploration

Participants were involved in the ideation process and were given the option to provide feedback as and when sketches were added. This was done using google drive. A folder was created to share work with participants. Participants were encouraged to check, and critique sketches every two weeks by adding notes to their specific doc files. This activity was continued over the entire ideation process (5 months) in order to allow the possibility of co-creation with participants and have their views herd as and when new ideas were being developed.

Smart Watch Competition

Through the co-creation exercise, the most prominent feedback was the concern that users may not want to buy a separate smart watch for this specific purpose. A common critique would be "why not just have it as an app on my apple watch?"

While it is true that existing smart watches do have all the capabilities needed for this system to work, there are issues with companies being willing to let third party ecosystems be included into their existing device and services ecosystem. As with smart device systems, due to differences in brand and dedicated parent device ecosystems, their communication beyond the specific brand is limited. For example, apple watches have NFC capabilities in order to make payments with the watch. However, Apple limits access to the NFC sensor for other third-party apps, especially ones that are not used for payments. Furthermore, as this concept demands for the creation of a pervasive ecosystem, existing smart watch manufacturers may decline the offer to incorporate it into their WT devices for safety reasons.

It would be a very interesting prospect to have this concept integrated into existing smart wearables that have the required sensing technologies. However, this is a long-term goal for the development of this concept. This pitfall, however, is a blessing in disguise as it allows for the concept to develop a WT form that can test the importance and influence of hedonic qualities of form and interaction for WT device adoption.

This critique does however shed light on a very important pitfall which is that users who already own a smart wearable will not want to invest in a second smart wearable of the same form. Especially one that needs to be worn at all times to function. While this helps strengthen the decision for a range of products that can satisfy different users' needs, it also opens up the possibility for an add on device that can be added to existing smart devices.

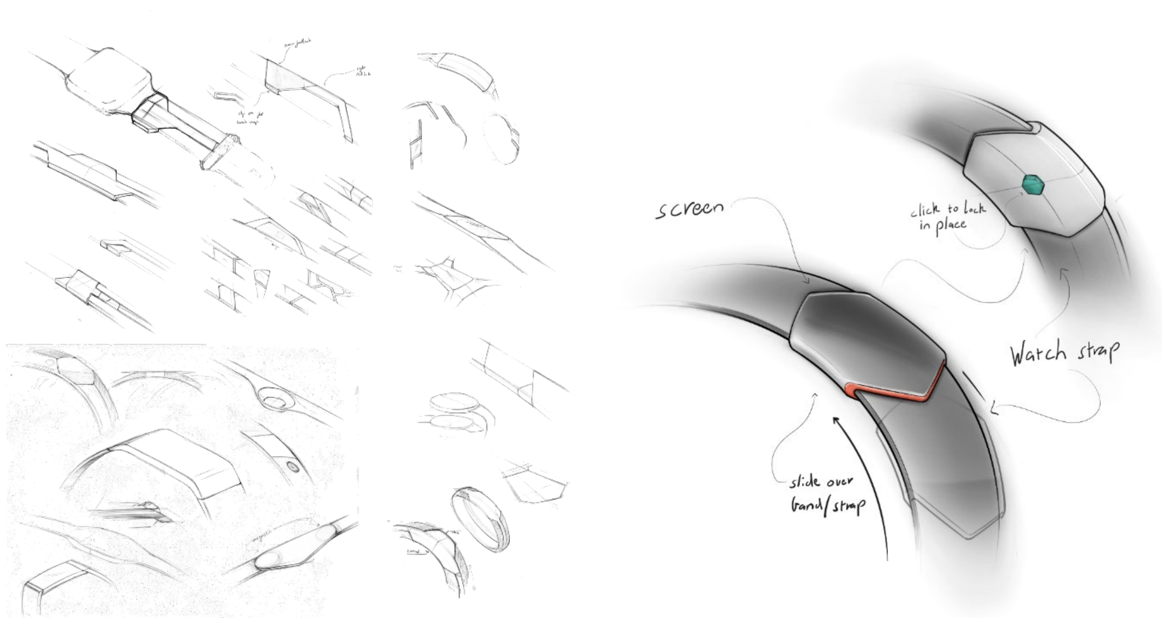

Figure 17: Watch Add-on Exploration

Take smart watches for example, there is valuable space available along the strap of the watch that can be used for the purpose of this concept. This area of exploration was short-lived however as most participants were not interested in an add on for a watch.

Another critique was that while participants were very interested in the ring option, there was very little screen real estate to work with. Furthermore, it was difficult to fit all the components within a form factor that small. As a result of this explorations were done to find an alternative feedback (screen) source for the ring. This led to the idea of smart glasses as a feedback device. Initially, glasses were not considered as an ideal form factor as research showed that the ideal location for the wearable is on and around the hand. However, when combined with a ring as the controller, the solution that emerged was a truly ambiguous system where manual input actions are performed by the ring and feedback is augmented into what users see around them.

This concept was very well received by participants of the cocreation exercise. It was in fact more appreciated over the watch form.

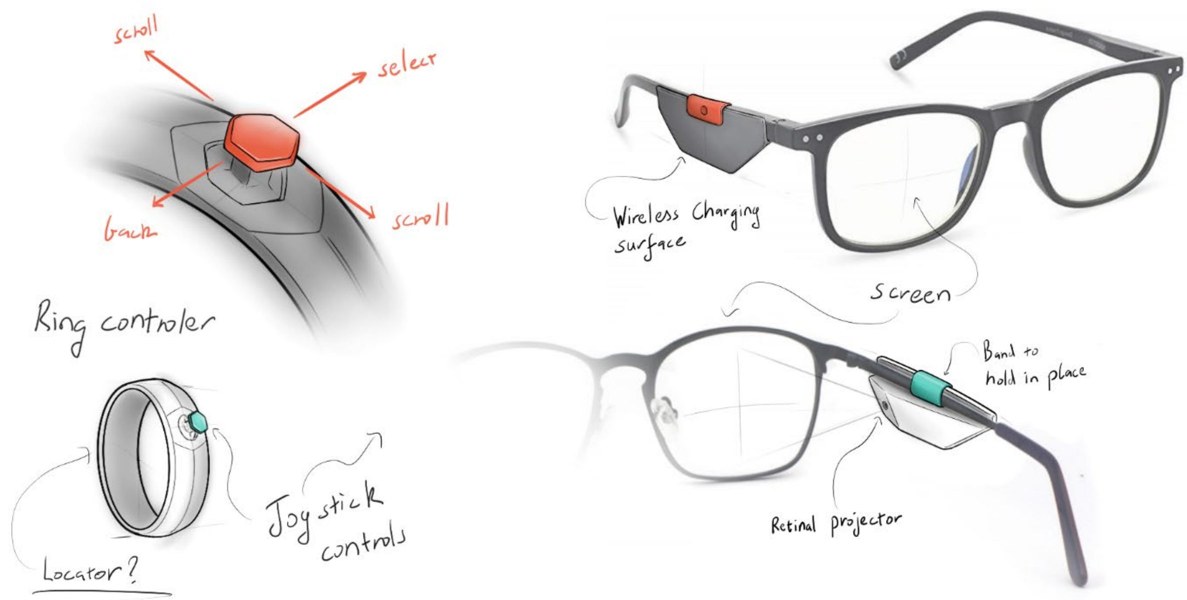

Figure 18: Selected form (Projector + Ring)

Retinal Projection

Retinal projection (RP) technology or virtual retinal display (VRD) is a technology developed by Dr. Thomas A. Furness at the human interface technology (HIT) lab to create images by scanning low power laser light directly into the retina (Virre et.al., 1998). This technology has been developed over the years and was finally miniaturized successfully by intel with the introduction of their Vaunt smart glasses that use a vertical cavity surface emitting laser and holographic grating (Bohn, 2018). This technology allows smart glasses to be more ambiguous by getting closer to the form factor of everyday spectacles and thus can be used to create an add on feedback device for the smart ring.

When it comes to eyewear design, there are many factors to take into consideration including style, shape of the face and prescriptions. As a way of avoiding these complexities, it was decided that instead of designing smart glasses, it would make more sense to develop an add on to regular glasses that would make them smart thus allowing the form to reach a larger market of potential users.

Hexagonal Design Language

As stated by Jonathan Ive in an interview with the guardian (2015), It's (apple watch) square because "when a huge part of the function is lists a circle doesn't make any sense". An article on CNET by Bhagat (2015) mentions that even smartwatch designers from Samsung acknowledge, round screens not only offer less space to display information but also make control of the touch-based interface more difficult compared with square screens. However, Kim K.J. (2016) in his paper comparing smart watch forms stats that Round screens, despite their negative effect on perceived control, can lead to a higher acceptance of smartwatches. This is driven by the social understanding that watches are round.

In order to create a balance between the two forms, a hexagonal form was taken into consideration. In a lecture by Dr. Prof. Danko Nikolic about differences between AI vs human brain (2020), he mentioned that most smart voice assistants today have a circular form for their logo and related this back to HAL 9000, a fictional artificial intelligence character and the main antagonist in Arthur C. Clarke's Space Odyssey series. Today, most voice assistants use a circular form to represent near human interactions with AI, whether it is represented through a visual logo or the shape of the smart speaker. A square or rectangular form on the other hand is used to represent technology and screen interactions. Humans are represented as circular whereas a square represents technology that is distinctly not human. A hexagon pays homage to the geometric and man-made feel of a square screen but also brings into consideration a visual similarity to the circular form that represents natural and human intelligence.

Further, the hexagonal form often represents interconnectedness in nature like that of a honeycomb structure and is also used to represent a carbon ring in chemical structures. This relates back to the idea of being human given that biologically we are carbon-based creatures.

Based on these theories, and the fact that it is closer to a circular watch form that has shown to be more accepted for wearable form, a hexagonal design language was chosen for the development of the form.

Based on findings from research and the cocreation exercise, three forms were selected as part of the range of WT devices. The band is a wrist wearable that is designed for those that already have a smart watch or want a form that is less conspicuous. It is the entry level product with a comparatively smaller screen, and it uses a ring controller that can be swiveled to scroll and squeezed to select. The watch comes with a larger 44mm hexagonal screen that creates a balance between a typical watch face but is still highly optimized for digital information. The watch uses a crown that performs the required control actions of scrolling, selecting and going back. The top of the line projector uses retinal projection to give the user a feeling that their ordinary glasses are a feedback screen and creates a truly ambient experience for the user. An additional control ring with a directional controls and sensing capabilities acts as the input modality for the Wearable.

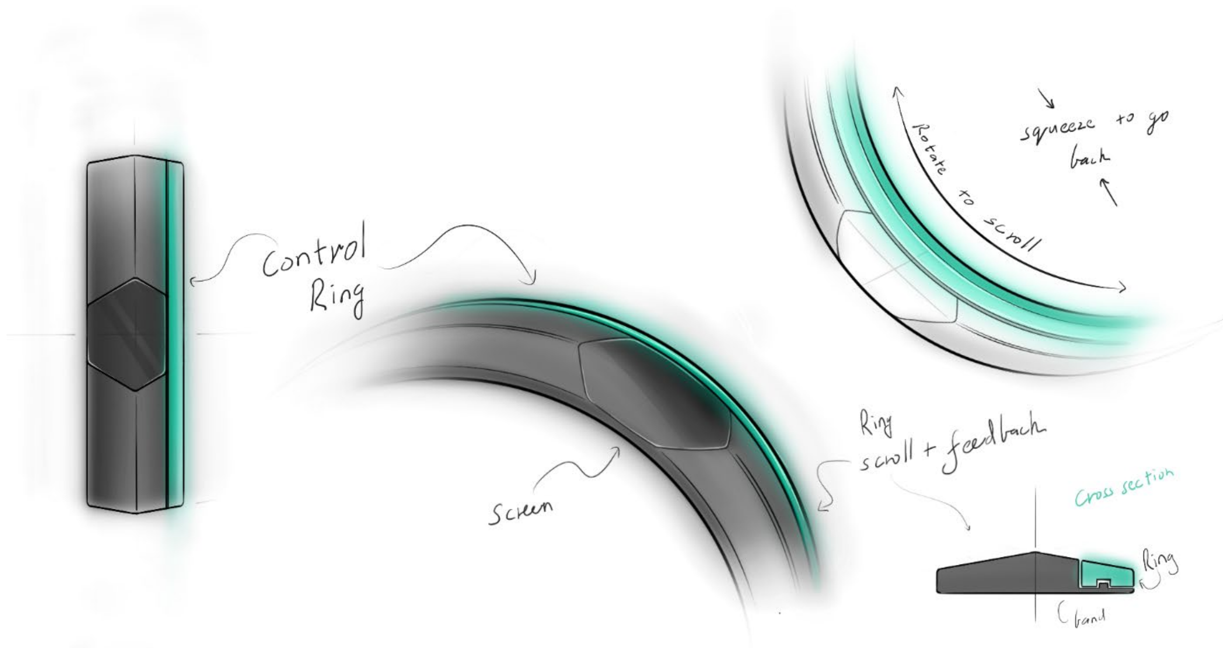

Figure 19: Selected form (Wrist Band)

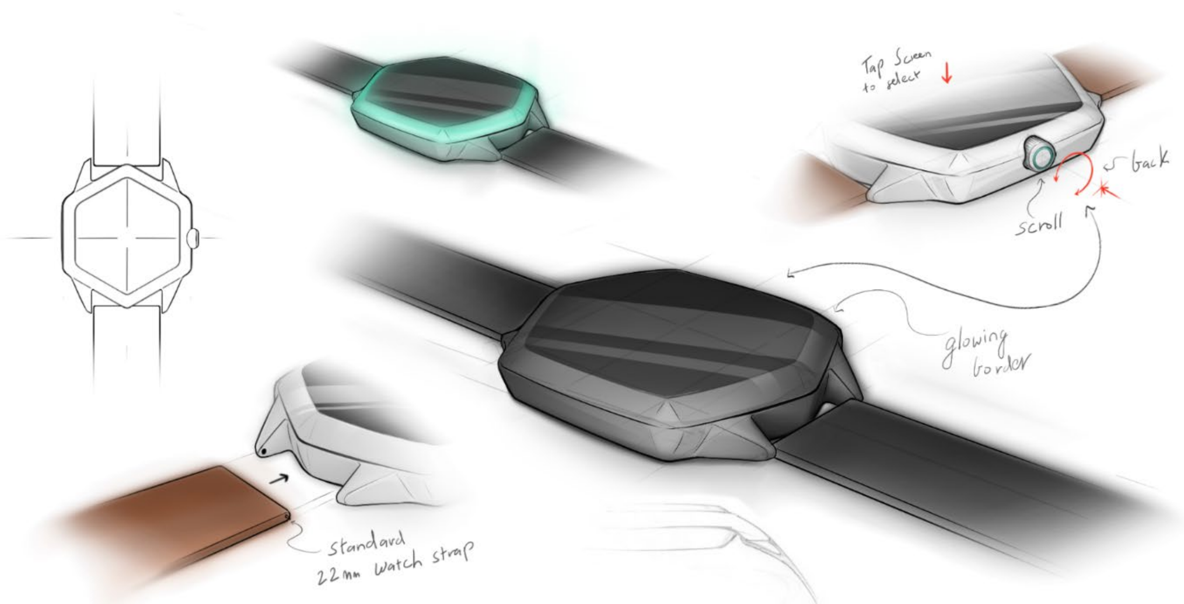

Figure 20: Selected form (Wristwatch)

Feedback Type

The WT devices provide feedback of HI actions in the form of light, vibration & screen icons. Sound feedback was not considered for this concept as it was considered disruptive for everyday activities (as seen with mobile phone notifications) and vibration was considered more subtle and personal to the user. Further, as the device is in direct contact with the user the vibration is more noticeable than that of a phone. The light and vibration are basic indicators of the fact that something has happened. They do not however give any specific information of what has happened. The screen icon on the other hand gives further information of which particular device is activated.

Color, Material, Finish

Given that the WT devices should to fit in with the user's style, it was decided that neutral colors will be used for the form. Shades of black and whit are universally accepted and neutral colors that match with everything and were used for the WT form.

Further, as the wearable should fit into both formal and casual scenarios, a metallic finish is selected for the outer shell material. This compliments the reflective nature of the screen and allows for the finish of the entire form to be consistent. For the other wearable devices, a combination of matte black and glossy dark grey is used to make the form less conspicuous yet technologically advanced.

The feedback light on the other hand needs to stand out and catch the user's eye. However, it must not be disruptive to the scenario and environment the at the user is in. the color seafoam was selected, as green is considered to have less strain on the user's eyes. This color is also used in many situations to represent aura of living creatures. It represents positive energy flowing through a being. For these reasons, a subtle seafoam colored glow was considered for the light feedback for the device. The seafoam color was further used sparingly on the controllers of the wearables to help users differentiate between the form and its moving parts. Further, this lets users subconsciously relate the color to an action being performed.

User Interface Considerations

Based on findings from this thesis, the main functions of the AmI ecosystem were identified and listed. These were: setting up & editing the ecosystem, controlling smart devices, setting up & editing preset routines triggered by HI actions and locating devices within the digital space. These functions were further broken down into a list of features for the system. These features were then grouped together to develop an architecture for the user interface.

As mentioned in phase 3, apart from the controlling smart devices function, which involves discrete actions, the other functions are complex and require an assistant app to be performed.

PHASE 5: Open Card Sorting

In order to gauge the user's mental model for using the interface, an open card sorting is conducted to gauge how the user sees the architecture and flows of information. The list of features is converted into individual cards and each one is given a description of the function and purpose. Users were asked to group these cards into categories and name each one. This was done to understand what types of information and actions users see as similar and identify where in the interface would they look for this information.

After grouping the feature cards, Participants were asked questions to help further understand the reasoning behind their decisions. For this card sorting exercise, Optimal sort, an online card sorting tool was used to help reach a larger audience. The data collected form the card sorting exercise was graphed using dendrograms to see which card groupings have the strongest agreement.

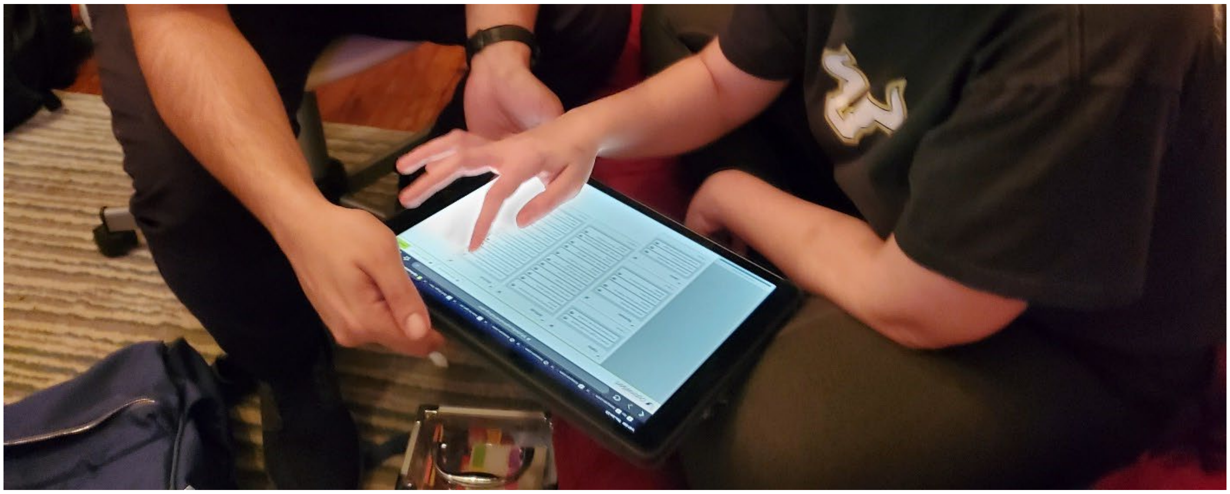

Figure 21: Card Sorting Exercise with Participant

Phase 5: Findings

It was observed that the features could be grouped into 6 groups: Home, Routines, Settings, Add, invisible actions and WT feedback settings.

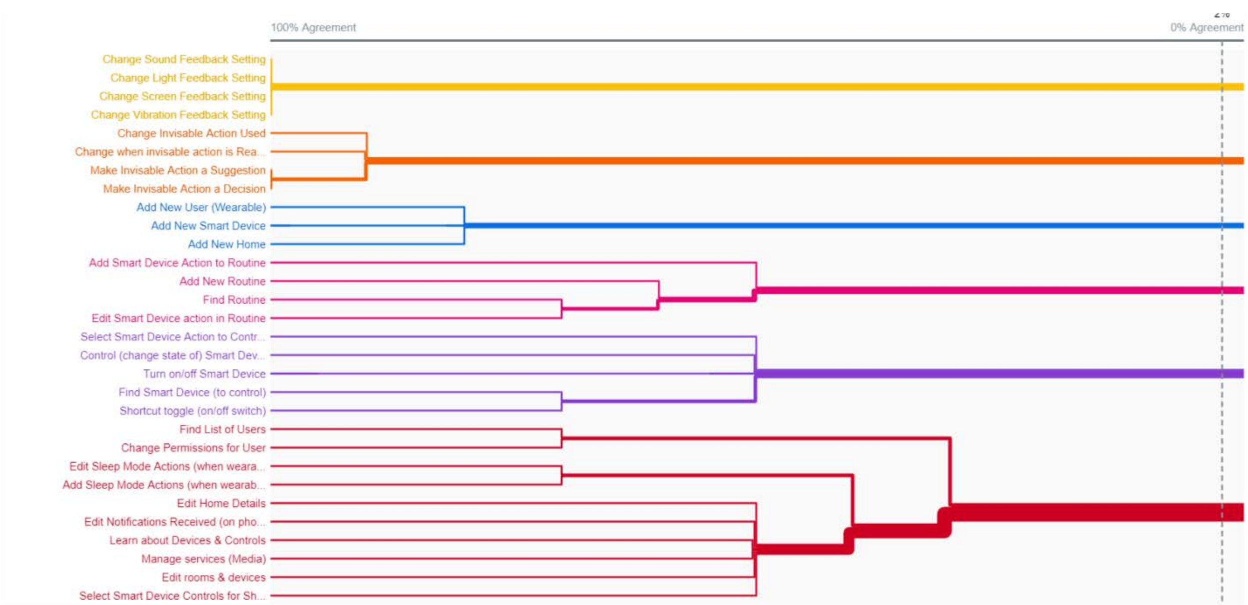

Figure 22: Card Sorting Dendrogram

Home consists of a list of smart devices that can be individually selected and controlled within the ecosystem. Participant feedback for this group focused on 2 things. Firstly, if there are too many devices, finding a specific device would be difficult. So it would be nice if there was a way to filter devices. Further, it would be nice if regularly used devices could be added as a shortcut for easier access.

The routines group focusses on features that involved setting up HI actions for the WT device, ranging from setting up new HI actions to adding devices to existing ones. It is also worth noticing that participants referred to HI actions as routines or cycles rather than actions. They saw these as repetitive actions that would be performed through the day. A participant also mentioned that this could be a space where all the wearable information exists.

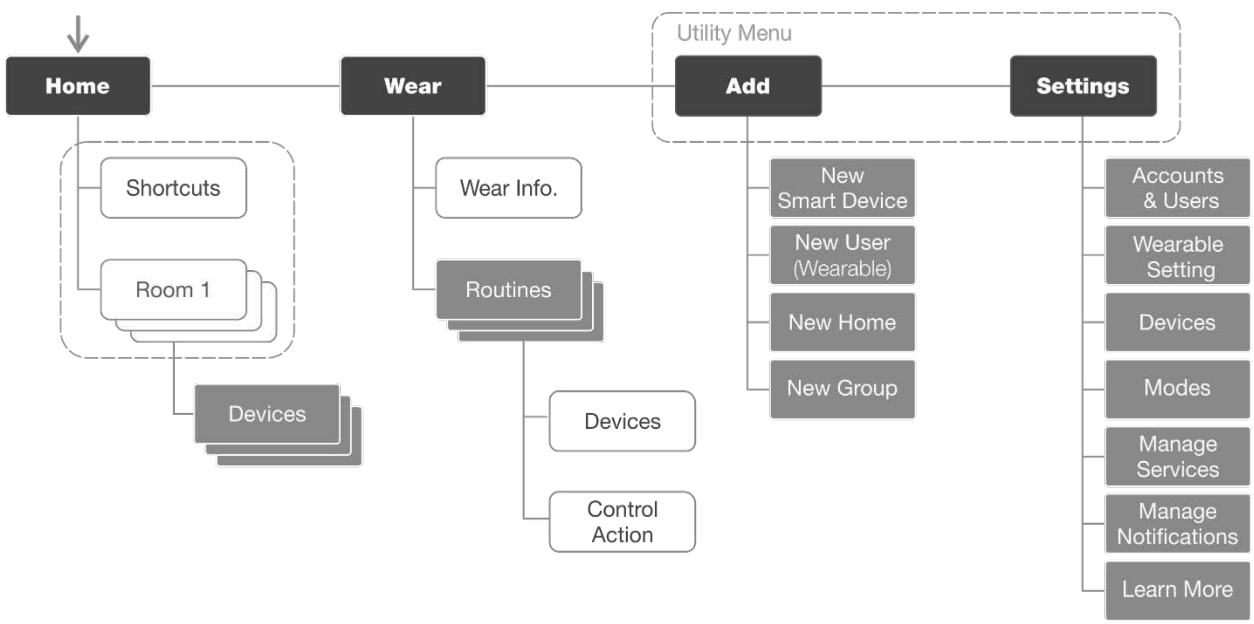

Figure 23: Higher Level Blueprint of App

It was interesting to see that participants also used similar words to group features. All the features that had the word ‘add’ were grouped together irrelevant of what specifically was being added. This led to the inference that add should be a higher-level menu that allows users set up new additions to the system.

Finally, the settings group consists of all the other features that focused on editing details about the ecosystem ranging from the home name to the types of notifications received. The WT feedback and invisible action settings were grouped as separate from settings. However, it is interesting to see that participants still use the word 'settings' as part of the group name. This led to the understanding that these could be subsets within the larger settings group and elements within the setting group can be further grouped into smaller subsets.

It can thus be concluded that the information architecture for this platform consists of the higher-level menus of home (smart devices list & control), Wearable (routines & WT information), Add (additions to the system) and Settings (everything else). Further, given that 'Add' and 'Settings' are used to edit the system as a whole, they can be further classified as utility menus.

Buttons, Colors & Icons

Given that the wearable has the smaller screen and more limitations when displaying information and feedback, it was used to develop the visual design language for the interface. Due to the small size of the wearables, it is harder to develop edge to edge screens as space needs to be assigned for the technology to run the screen. As a result of this, a dark background was used to blend the screen with the rest of the form to give it a smoother transition.

A darker background further helps the information on the screen to pop allowing it to be clearly visible without putting too much strain on the eyes and also helps save battery power as pixels for the background are not emitting color. Google's material design UI kit template for dark theme was used as a reference for developing the UI for this platform.

Information and icons use white to stand out against the darker background. They are used at 100%, 70% and 35% opacity to show active, inactive and deactivated states respectively. Due to the small real estate, the Icon style is light and uses line art icons. Solid seafoam color is also used to show that an icon or text is in the on or selected state. The color is used sparingly to maintain the airiness of the icons. Roboto font is used for all text as it is a clean and simple form that is easy to read.

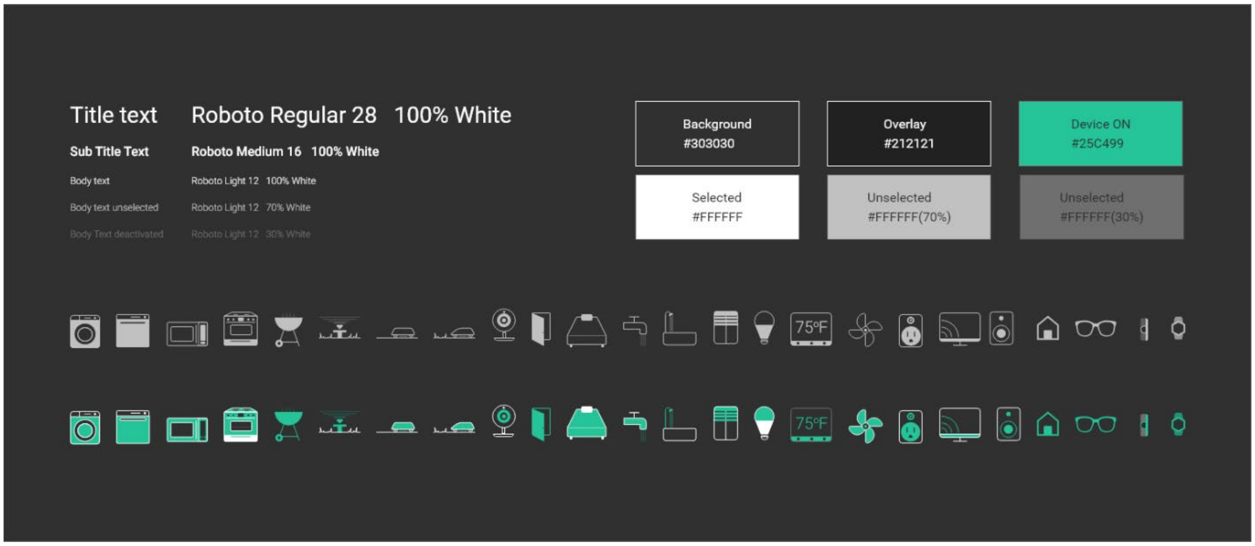

Figure 24: UI Style Guide

WT Interface Development

As mentioned earlier in this thesis, the wearable has two major functions: HI actions that are triggered when the user walks through the environment and manual control that allows the user to alter the state of a smart device within an ecosystem himself. The HI actions can further be separated into decisions that trigger changes in smart device states without need of user intervention and suggestions that require the user to approve the changes that the HI action suggests.

Further as observed through this thesis, feedback needs to be provided that clearly indicates a change in smart device state. Based on these criteria, a state diagram was made to map how these functions and features would be laid out and how the user would navigate through the UI.

As observed in findings from the tabulated data from phase 3, devices can be categorized by their location and state. It was also noted that a user may have multiples of the same device.

For example, a user may have a TV in the living room and the bedroom and multiple smart lights around the house. In a situation where a user has a few devices, finding the right one is not as hard. As this number increases though, it gets harder to find a specific device. As a result of this, searching for a device by location makes this process easier as there is a lower chance of repeating devices within the same room. The device naming process also becomes very important in order to clearly differentiate devices to avoid confusion. As a result, focus must be given to the unique naming of each smart device during the setup process.

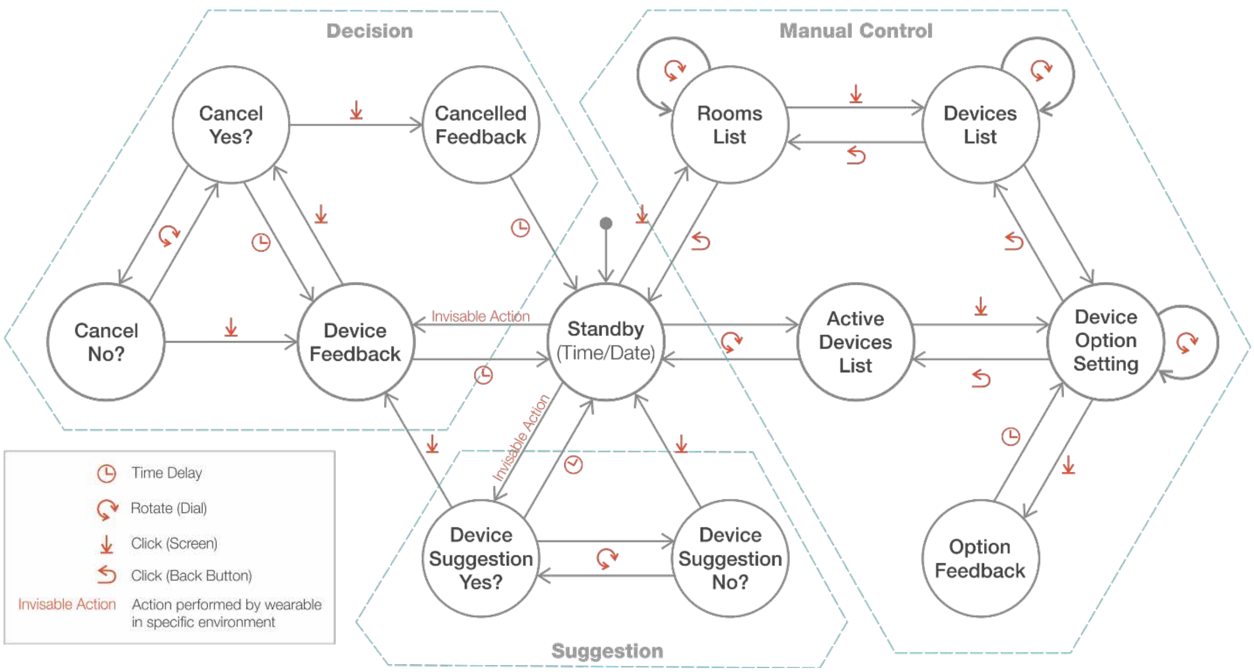

Figure 25: UI State Diagram for WT

Further, some devices need to be accessed quickly if they are turned on by mistake, especially id the effect of the device is highly undesirable. There is therefore a need to quickly access active devices and bypassing the searching and filtering process. For this reason, the active devices can be accessed from the default screen.

Mobile App Interface Development

Based on findings from the card sorting, lo-fi wireframes were developed to show flow through the UI for 6 scenarios: find and change state of a device, find users within the system, edit a routine, set up a new device, add a new user and access settings.

As this is a mobile app UI, tabs, lists and grids were used as layout elements for the information. The UI has two tabs at the bottom of the screen, one for the home and devices within it and one for the wearable and its routines. The utilities: add and settings, are placed on the top left and right corners respectively to visually separate them as higher level in the information hierarchy. Each page follows the layout order of header, quick access toggle switches and grid/list.

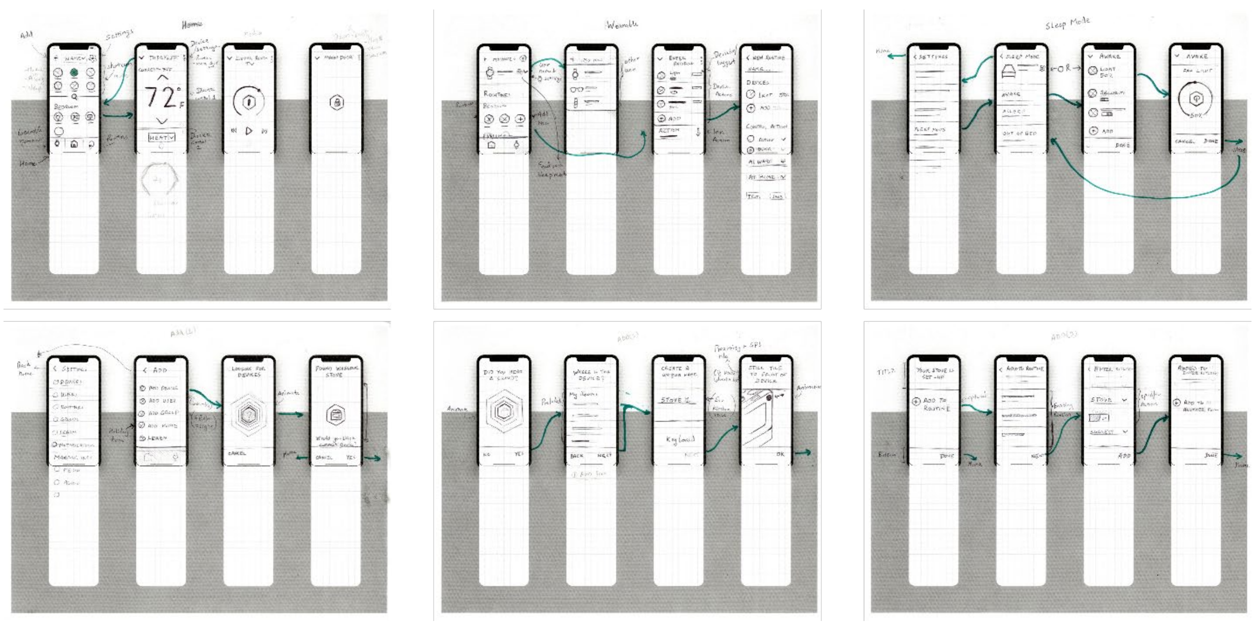

Figure 26: Lo-Fi Wireframes for App

For individual smart device pages, the information is in the center of the screen and can either be a single discrete button, discrete button and variable control or discrete button, variable control and media controls. The hexagon shape is used wherever possible to link it back to the form design language. As the setup and add scenarios were sequential processes that followed a step by step flow, these also helped gain insight into the complexity of the set-up process. The Lo-fi wireframing exercise helped further eliminate unnecessary steps and narrow down to the necessary information required to make the process easier.

PHASE 6: Quasi-Empirical User Testing

The next step was to develop a digital prototype for the UI to test interaction flow and validate design via user testing. As the app works as a failsafe device in case of wearable failure and is further used for the more complex set up tasks, it is tested separately from the rest of the ecosystem to ensure that it can work without use of the wearable. Quasi-empirical user testing was conducted to gauge if the app design and flows match the users' mental models.

For this study, apart from testing with the existing sample set of participants, the scope was increased to any person. This was done because while the existing sample set was a useful source of information, they were involved in the development of the platform via the co-creation exercises. As a result, it became imperative that the platform be looked at with a fresh pair of eyes so that previous bias does not affect the validation process. For this study a new sample of 30 participants ranging in age, gender and ethnicity were used.

Participants were given a phone with a preloaded prototype of the assistant app and were asked to perform tasks based on the scenarios used in the development of the app one after the other. While performing these tasks, they recorded for time taken to process the task and time taken to find and perform the task. After they were done performing these tasks, they were asked what problems they faced and confusions they had while using the app. They were also asked to fill out a survey to help gauge the system usability scale (SUS) score for the app. The entire exercise took an average of 15 minutes per participant. Data collected was analyzed to identify voiced user confusion while navigating the UI. Feedback provide was also mapped against level of importance and influence to gauge priority of the change requested.

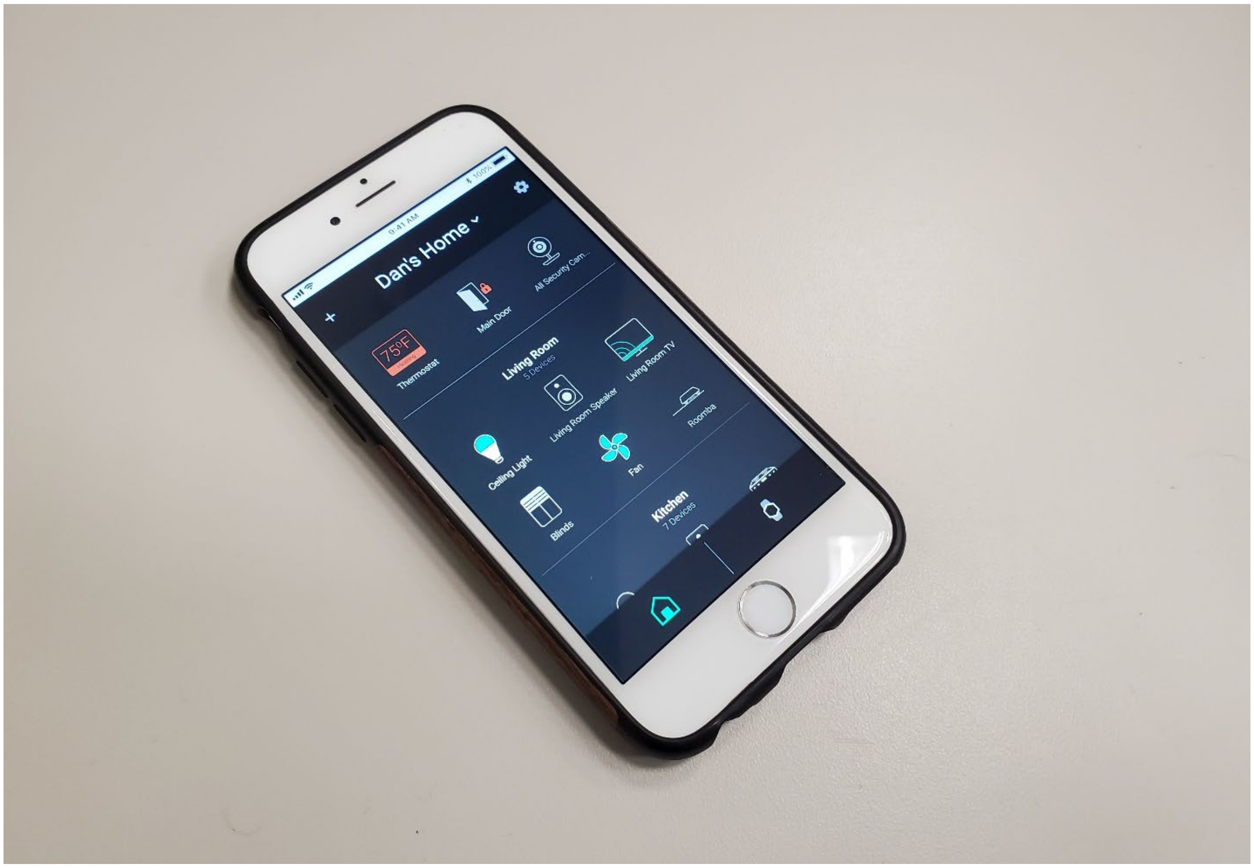

Figure 27: App Prototype used for User Testing

Phase 6: Findings and Edits

Overall, users got through each task within a 5-12 seconds. They had no problem understanding the layout and functions of the various elements of the UI. Overall the app got a SUS score of 92 which is considered acceptable for use. Most of the participants found the app user friendly and icons conveyed their purpose clearly.

The most prominent flaw in the UI flow observed however, was that participants could not figure out how to add new users (wearables) to the ecosystem. Only six of the thirty participants performed the task successfully on the first try. Nine, performed the task after further explanation was given. The remaining fifteen could not perform the task at all. While it was easy to add and set up new smart devices through the add utility menu, participants did not think to look in the same place to find the add new user option. They instead looked for it in the wear tab on the app or in the settings utility. The reason for this was that they saw this function as a higher-level function that is not the same as adding other devices. This is an important task for the system and therefore requires a high level of attention. To help users with this, an add option is added to the 'list of users' dropdown menu in the wearable tab and to the settings utility so that users have multiple points of access to this function and can use the one that is most comfortable to them.

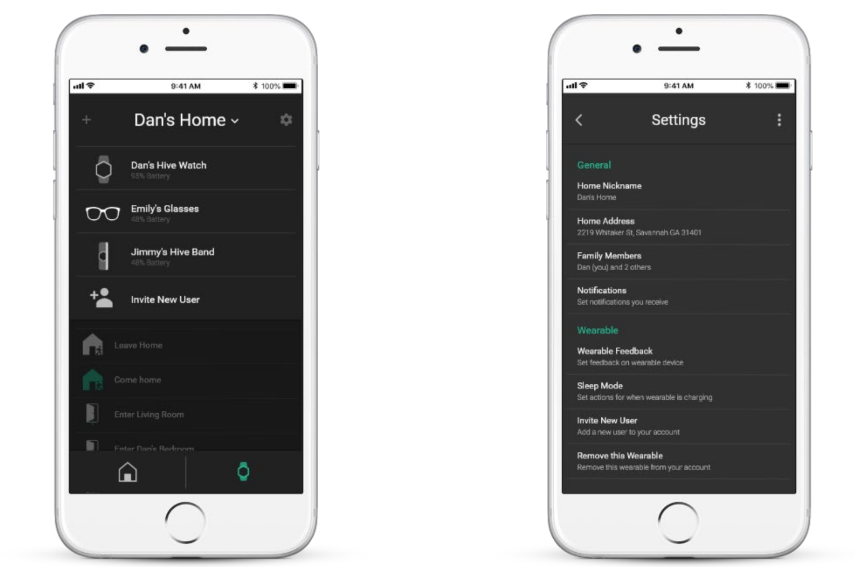

Figure 28: Multiple methods of adding New User

Another common fear was the number of notifications delivered to the phone every time the use performed an HI action. To help reduce the phone buzzing every time the user moves through the house, it was decided that HI action feedback would be limited to only the wearable. The state of the device would change from inactive to active on the app, but it will not provide any feedback that would draw the user's attention. Further, a control can be added to the settings utility that allows users to control the kinds of notifications they receive on the phone and similarly they can edit the types of feedback they get on the wearable. So, for example a user can choose to get no notifications on the phone and set the wearable to vibration and screen feedback only (deactivate light feedback).

There was also feedback about being able to access more information for smart devices through the app. This was majorly in relation to smart devices like security cameras where the participant wanted to see what the camera was recording in real-time. This app does not have the capability to do this. However, there is a possibility to include a shortcut that allows the user to open the parent app through the smart device page and access these functions there. This is however not a high priority change for this thesis and can be implemented at a later stage.

Based on priority, these changes were implemented to the UI for development of the final concept and validation.

Hive Mind (Final concept)

For this concept, I chose the name 'Hive mind' to build on the idea of a hexagonal design language. Webster defines the term hivemind as the collective mental activity expressed in the complex, coordinated behavior of a colony of social insects (such as bees or ants) regarded as comparable to a single mind controlling the behavior of an individual organism. This relates to what this thesis is trying to achieve where the user is the single mind controlling individual smart devices.

This concept aims at developing an improved method of interaction with Ambient Intelligence Environments (AmI) to enhance human experiences in daily life. The application of Human Interface actions creates a more intuitive and natural system of interaction using Wearable Technology more effectively in the home environment.

The hive mind ecosystem consists of the hive app, that helps the user set up and connect to existing smart devices in the home and a range of WT devices, one of which you can chose from to control your smart home without having to interact with traditional Screen or audio input modalities.

Figure 29: Hive Mind (Family of Products)

Hive mind is more than just another wearable. It is the key to your home. ***Hive Wear*** performs smart device tasks by reading invisible human actions and relative position thus making the user the center of interaction. It also provides feedback of invisible actions and manual control of smart devices to help build user trust in the technology & compensate for human tendencies

The range of WT devices consists of three options that users can chose from based on their personal style, existing accessories and level of ambient interaction they are comfortable with.

Hive Band

The hive band is a sleek 10mm wide, 65mm diameter silicone wrist band with a 25mmx15mm cut hexagonal feedback screen. The controller on the right of the band is a digital ring that can be swiveled to scroll and squeezed to select when a routine is performed, the digital ring glows to tell the user that an action has been performed.

A screen digitizer, printed PCB containing an NFC sensor and Wi-Fi receiver among other electronic components, the battery and sensors that collect body readings through the wrist are all held together under the screen by a bracket and the lower casing. This base wearable model is a compact and simple form that blends fashion and technology seamlessly.

Figure 30: Hive Band (Form, Controls & Exploded View)

The band can perform two major tasks: Provide feedback for HI decisions and suggestions and manually find and control smart devices by searching for them through the home or scrolling through active devices. The UI uses scrollable list layout that focuses the selectable object in the middle of the screen to create semantic consistency between the control and the screen.

Hive Watch

The hive watch comes with a larger 44mm hexagonal screen and a much more popular form factor. The watch is designed in a way that it can use any third-party wristwatch band thus allowing the user to customize it to their own personal style. The watch dial itself is available in deep grey and silver colors.

The watch uses a crown that performs the required control actions of scrolling, selecting and going back. It works exactly like a watch crown does to create familiarity of interaction. The angled bezel of the watch allows for easy access to the crown from any angle. The watch has the same internal components as the Band. However, due to the larger form factor, it can house a larger battery that can last for days.

Figure 31: Hive Watch (Form, Controls & Exploded View)

Like the band the watch can perform the tasks of providing feedback and manually controlling smart devices. The UI uses scrollable list layout that focuses the selectable object in the middle of the screen to create semantic consistency between the control and the screen. The transitions between pages are also consistent with the pushing action of the watch crown to create more fluidity between the screen and off-screen controls.

Hive Lens

The top of the line Hive lens is an add on to regular glasses that uses retinal projection to give the user a feeling that their ordinary glasses are a screen. The add on is 72mm x 20mm x 13mm in size and follows the contour of the cheeks to provide a comfortable fit. It can be attached to the right arm of any glasses using an adjustable hook and loop leather strap from which it hangs. When worn, the lens hangs off the arm and rests against the face. It can be moved forward or backwards to accommodate for different face types.

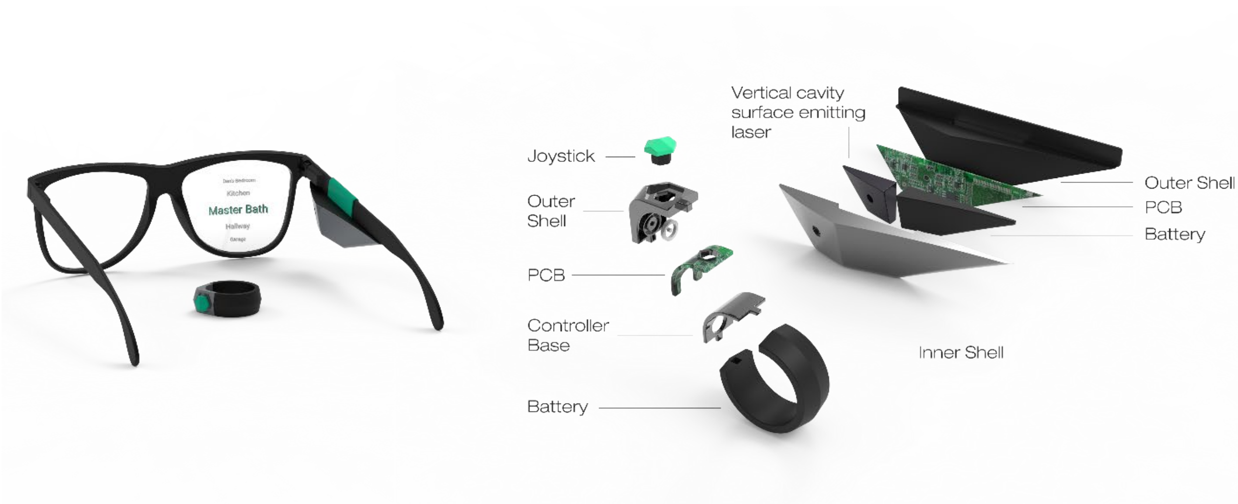

Figure 32: Hive Lens (Form & Exploded Views)

The hive lens comes with a control ring that can be worn on the pointer finger of the dominant hand and uses a directional joystick control to navigate through your smart devices with ease. The circular form has a protrusion where the joystick sits in order to let users locate it with ease without having to look at it, allowing the interaction to be less noticeable.

The projector houses the body reading & NFC sensors and battery for the projector. The ring on the other hand consists of sensors and controller PCB. The ring can be divided into two parts the controller and battery band. The band can be switched out in size to get the perfect fit that the user desires. The projector acts as the feedback and output modality for HI actions. Manual control can be accessed by using the joystick on the ring.

Hive App

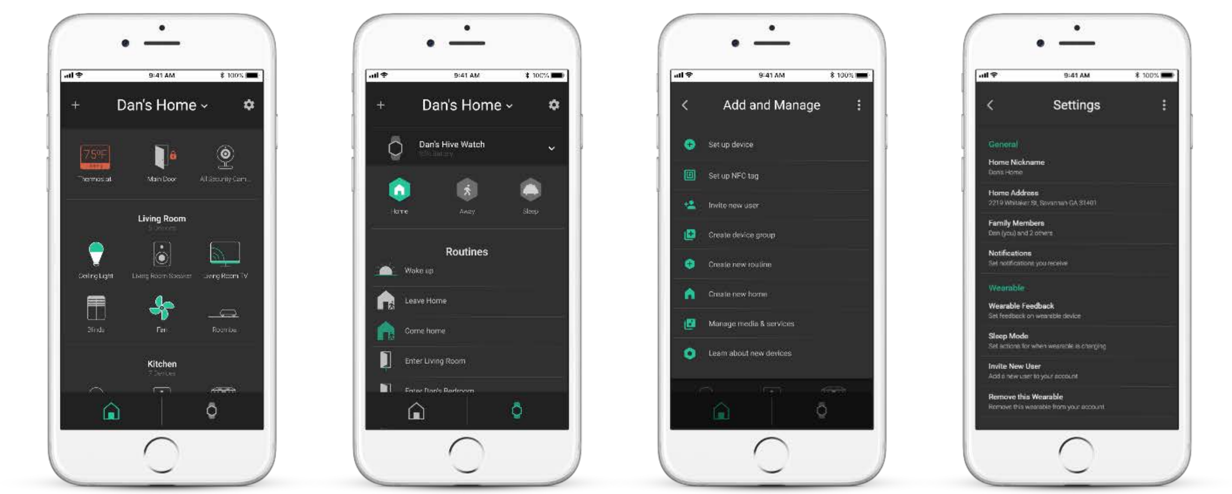

Figure 33: Hive App (Home, Wear, Add & Settings Pages)

The Wear comes with an assisting Hive App that acts as a fail-safe for the Wear and performs more complex actions like setting up new devices & wear routines. The "Home" tab displays all connected devices, segregated by room that can be controlled through the app via: Discrete Control, Discrete + Variable Controls or Discrete + Variable + Media Controls. Additionally, there are (user generated) device toggle shortcuts at the top of the page for quick access to certain devices.

The wear tab shows users (and their wear devices) connected to the home. Next, it shows the mode that the wearable is in, based on its state: Home, Away or Sleep (charging). Followed by the modes is a list of "Routines" that are activated by the wear device when performing specific actions. These actions, and the devices they control can be set here in this tab.

The dedicated "Add" button on the top left corner of the home tab allows for quick set up of new devices, wear devices & routines. Additionally, these can be added from settings menu on the top right. Routines can also be added/imported within the set-up process to save time and effort.

Prototype and Concept Validation

PHASE 7: Wizard of Oz Prototyping

The goal of this thesis is to create a pervasive system that makes technology more accessible to people by focusing on environment interaction instead of device interaction. The hive mind ecosystem attempts to do this by introducing a WT device that uses an HI input modality to bring humans to the center of interaction with the technology around them.

In order to prove that the proposed solution addresses this, a validation exercise is conducted to gauge user acceptance of form, and interaction within this system and identify possible flaws and pitfalls that could lead to failure. Prototypes of the ecosystem were developed to assist with the validation process.

Figure 34: Physical Prototype Development and Testing

As the prototypes are only for aesthetic purposes, a wizard of oz (WOz) prototyping technique was used was used in order to test user reaction to the proposed solution, where a researcher (the "wizard") simulates system responses from behind the scenes, while a participant engages with a system that appears to be real (Martin B. & Hannington B. 2012. p. 204). Participants were asked given a hive device and were walked through the app in order to let them get familiarized with the different preset routines. They were then asked to walk through the pre-set home space. A moderator walked along with the user to simulate system responses of the wearable on a phone screen while the wizard simulated the smart device changes around the home. These changes were determined based on future scenarios of the experience maps created based on findings from phase 3.

Data was collected in the form of observations and was analyzed to identify patterns in behavior among participants and gauge user acceptance. Using the WOz technique helps gauge how people will feel about—and how they might perform while using—a proposed solution (Martin B. & Hannington B. 2012). This exercise was done with both sample sets of participants.

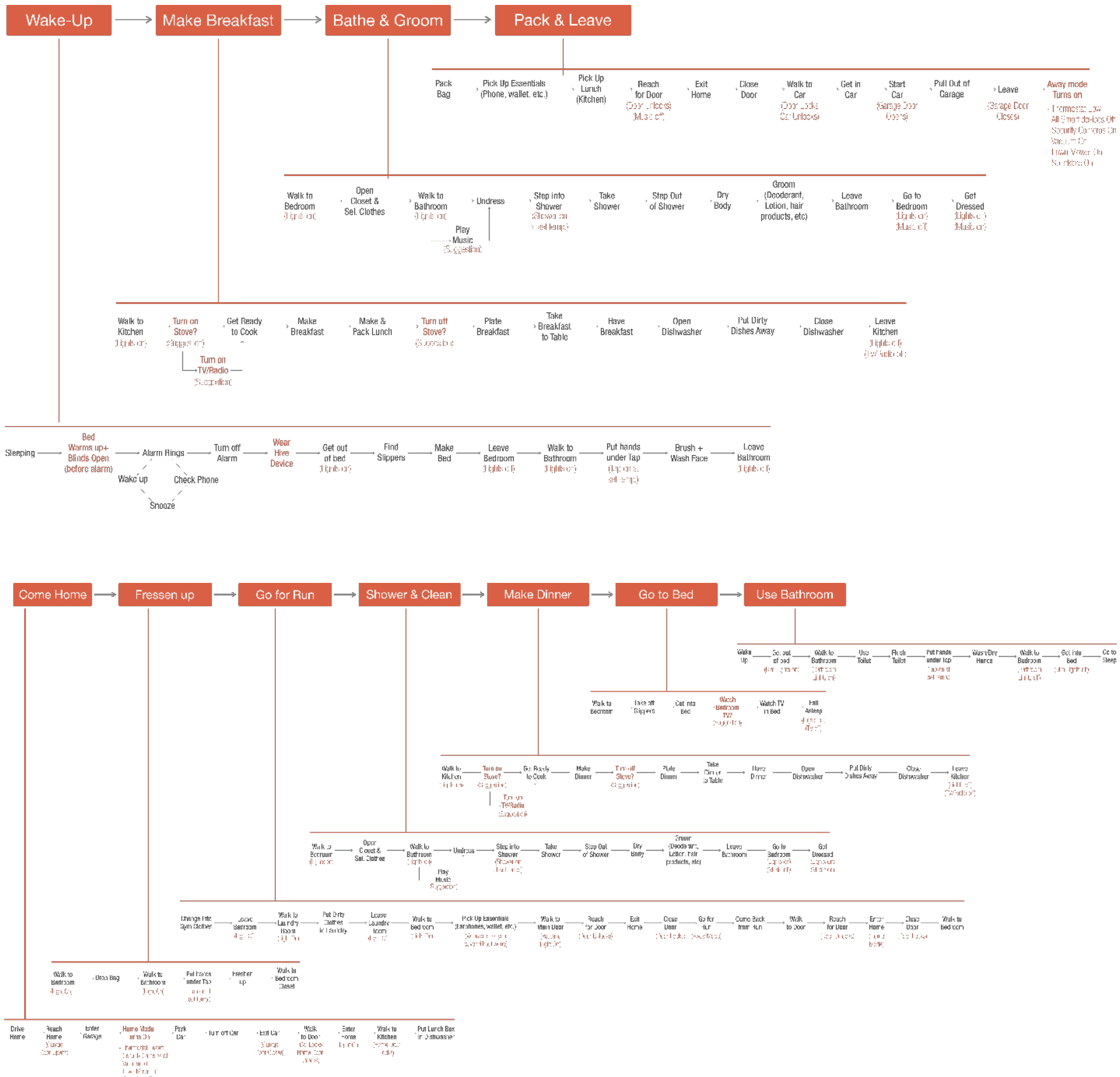

Figure 35: Future Scenario Maps

PHASE 7: Findings

Data from the WOz prototype showed that while most participants were comfortable with interacting with the system, they still had a few fears and frustrations that revolved around complexity and connectivity.

A common worry was the fear that this system will not integrate with user's existing smart systems. A participant mentioned, "will this work with my Alexa?". In an ideal situation, it will. However, there is need to approach these companies that develop smart devices in order to ask for permission to let the device integrate into the system. This will be true of all smart devices ranging from smart bulbs to smart refrigerators.

Further, another worry was how this system will work when multiple users are involved. The probability that there will be only one user living alone that will be the system by themselves is low. It therefore must be taken into consideration that it will become more complicated to keep track of and control the states of multiple devices as the number of users grow. For example, if the routine for one user involves turning the thermostat up when they arrive home and the routine of another user is to turn the thermostat down, what happens if both users arrive at the same time? This problem is in fact not even one that is limited specifically to this project. Even without the use of the hive ecosystem, users have individual preferences and it therefore becomes important to further study human behaviors when living in the same space and how decisions are made regarding shared utilities within a home. For this current system however, a possible solution is to provide a system error showing that the routine cannot be set as someone has already set an ideal setting for a smart device within a specific routine, which will force the two users to discuss the matter over in person.

This also leads into the most commonly expressed fear of system failure due to irrational behavior and how the system deals with it. A specific example from one of the participants was "what if I walk into my home at 2 a.m. and I have a routine set to turn on the passage lights when I enter the home?"

In this situation, the system allows the user to set when the routine will work and when it will not. For this specific example, if the routine is set to work only before 11:00 pm the system will not let you in and you have to manually control the door to open. Alternatively, the passage light action can be changed to a suggestion instead of a decision so that the wearable asked if the user wants to turn on the lights. Finally, if coming home at 2 am is a regular event, it is possible to create a new routine for that action that is specific to that user only. Thus, making the routine and in turn the entire ecosystem very personalized and customizable.

Limitations of research on page 27 and findings from Phase 1 helped identify that user trust in technology is the biggest barrier to overcome when it comes to acceptance of new technology, followed by a disruption in what is considered normal in current society.

The physical design of the hive wear, when compared against the same compared against the same 12 parameters to help gauge user acceptance, had a much higher level of acceptance compared to devices used in phase 1.

Participants also showed interest in the idea of a connected ecosystem and were accepting of the HI input modality used. The Proposed input modality allows this system to overcome the shortcomings of AI by leveraging human presence to make up for AI's inability to understand context. There is still however, a lack of trust in the system as a whole to function as advertised. This is not surprising as any new technology, in its early stages is questioned. Smart systems in particular are feared given that even thinkers like business magnet Elon musk and the late physicist Steven Hawking foresee a dystopian and possibly violent AI take over that may eradicate human society (Falls S. 2018).

It should be noted however, that participants showed a higher level of acceptance to this solution as a whole compared to the pre-determined scenarios from phase 1. It can therefore be concluded that there is a high possibility of this concept being accepted as the finer details of ecosystem function are worked out.

Discussion & Conclusions

This thesis investigates dimensions of interaction & user experience of WT and its effect on user acceptability, within an AmI system, that improve the experience of daily activities. The goal of this thesis was to create is to create a pervasive system that makes technology more intuitive and accessible to people by focusing on environment interaction instead of device interaction. This thesis proposes a WT device that creates a high level of ambiguity while keeping user trust in the system intact so that it is adopted faster into the current status quo of acceptable technology.

While there are issues that need to be addressed further, it can be concluded that the use of Human Interface input modalities are a possible solution to overcoming the limitations of AI within Ambient intelligence spaces and have the potential to help push the boundaries of AI systems further.

Further while AmI spaces already exist in our daily lives, they are not truly connected ecosystems that communicate with each other can leverage information from each other to overcome existing shortcomings. A truly connected AmI ecosystem will allow for a new generation of smart spaces that help improve quality of life and let humans focus on what matters most to them.

Further Study

This thesis provides an initial set of principles that help build a criteria list for the development of wearables to function as communicators within AmI Environments & defines parameters to assist adoption of invisible technologies. However, further research needs to be done in these specific avenues that were highlighted in this paper. As seen in findings from the validation study, it is important to further study human behaviors when living in a shared space and how decisions are made regarding shared utilities within a home to further understand how to deal with complexity of actions within an AmI ecosystem.

Further, while this thesis focuses on moving away from screens and making humans the center of interaction, there is still a need for some screen interactions in order to set up the AmI ecosystem, which seems counter intuitive. This is because screen interaction has been used as the primary form of interaction ever since digital technologies were invented and much more research needs to be conducted before we can completely move away from the concept of "adapting to the machine in front of you."

Glossary

Ambient Intelligence (AmI)

Ambient Intelligence (AmI) represents a new generation of user-centered computing environments aiming to find new ways to obtain a better integration of information technology in everyday life devices and activities (Jose, B. et al. 2011). AmI environments have devices of modern life that are fused with computational technology and sensing capabilities. Ideally, people in an AmI environment will not notice these devices, but they will benefit from the services they provide them (Jose, B. et al. 2011).

Artificial Intelligence (AI)

AI is a branch of computer science dealing with the simulation of intelligent behavior in computers, giving machines the capability to imitate intelligent human behavior (Artificial intelligence, n.d.). The area of Machine Learning (ML) is a core element of Artificial Intelligence (AI) Systems. The technology adapts to patterns observed from collected data (behavior) to create a "knowledge system" and predict possible scenarios.

Autonomic Nervous System (ANS)

A part of the vertebrate nervous system that innervates smooth and cardiac muscle and glandular tissues and governs involuntary actions (such as secretion and peristalsis). It consists of the sympathetic nervous system and the parasympathetic nervous system (Autonomic nervous system, n.d.).

Emotion-Aware (EA) computing

Emotion-aware computing allows a sensing device to have the ability to recognize the emotional state of humans through gesture/expressions, voice tone/pitch and ANS; and gives an appropriate response to these emotions. Emotion-aware computing can offer benefits and play an essential role in an almost limitless range of applications that involve machine learning (Babiker et al. 2015).

Human-Computer Interaction (HCI)

The Association for Computing Machinery (ACM) defines human–computer interaction as a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them (Hewett, T. et. al. 1992). Input in humans occurs mainly through the senses and output through the motor controls of the effectors. Vision, hearing and touch are the most important senses in HCI. The fingers, voice, eyes, head and body position are the primary effectors. (Dix, A et. Al. 2005)

Human Interface (HI)

A method of interaction that uses human attributes like, gesture, location and biological readings to control the AmI environment around them. The human interface approach builds on the idea of skipping menial micro-actions and takes it a step further. It clubs together actions performed, into one unnoticeable action, thus hiding these menial micro-actions from the user. In essence all the actions are still being performed. However, they go unnoticed by the user.

Internet of Things (IoT)

In the broadest sense, the term IoT encompasses everything connected to the internet, but it is increasingly being used to define objects that "talk" to each other (Burgess, M. 2018). IoT is the networking capability that allows information to be sent to and received from objects and devices using the Internet. Daniel Burrus mentions that, “The real value that the Internet of Things creates is at the intersection of gathering data and leveraging it.” (Internet of Things, n.d.).

Machine Learning (ML)

Machine Learning uses the theory of statistics in building mathematical models, because the core task is making inference from a sample (Alpaydin, E. 2014). It is simply an algorithm, based on past data, to identify patterns and predict futures. Machine learning allows technologies to achieve a level of clairvoyance in the decisions that humans make and complete (or suggest) actions without much intervention needed from the user.

Quality of Life (QOL)

Quality of life is subjective and multidimensional, encompassing positive and negative features of life. It's a dynamic condition that responds to life events. Simply put, Quality of life is the standard of health, comfort, and happiness experienced by an individual or group and indicates of how good or bad a person's life is (Quality of Life, n.d.)

Wearable Technology (WT)

Wearable technology is a form of Assistive technology that is used to increase, maintain, or improve functional capabilities to make the completion of a task easier. It can be broadly defined as any form of technology that that is worn by a user. A common example today is the smart watch that is used as a companion device to the mobile phone.

Ubiquitous Computing (UC) / Ubicomp

Ubicomp is essentially a human-centered approach, to interacting with technology put forth by Mark Weiser (1991) that is based on the concept of invisibility (Kerasidou. & Charalampia, X. 2017). The idea is to move focus away from the machines and the technical, and instead concentrate on people and the social environment. In Weiser's words: "Machines that fit the human environment instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods." UC focuses innovation away from emphasis on the machine and back to the person and his or her life in the world of work, play, and home'.

User Interface (UI)

The interface features through which users interact with the hardware and software of computers and other electronic devices (User Interface, n.d.). The most popularly used UI today is the graphic user interface (GUI) which is a computer program designed to allow a computer user to interact easily with the computer typically by making choices from menus or groups of icons.

Wizard of Oz (WOz) prototyping

Wizard of Oz (WOz) prototyping is a research technique used in order to test user reaction to the proposed solution, where a researcher (the "wizard") simulates system responses from behind the scenes, while a participant engages with a system that appears to be real (Martin B. & Hannington B. 2012. p. 204)

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