MEDIATED REALITY IN BEARABLE PROSTHESIS: A TOOL FOR SURVEILLANCE AND INTERVENTION

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Abstract

The thesis interrogates Reality through experimental prosthesis. Establishing distinct terms as means of understanding the topic; Mediated as opposed to Augmented Reality and Bearable as opposed to Wearable prosthesis.

Augmented Reality traditionally refers to the overlaying of dynamically changing information onto user's senses, emphasising primarily on the visual aspect of sensory enhancement. Mediated Reality, on the other hand, as defined in this thesis, supercedes Augmented Reality in that it refers to the artificial modification of human perception by way of devices used to deliberately enhance or alter our senses. While there is some crossover between the terms Augmented and Mediated Reality, which are often used to describe the effect of technological devices found carried with or attached to the body of users. Mediated Reality provides a more immersive experience for the user, employing a wider range of user's sensory input and forms of feedback.

Bearable prostheses include all types of implantable, portable or body-borne computers that are embedded on or in the body.It goes one step beyond Wearable prostheses which are worn under or in the clothing, or are integrated into the very fibres of the clothes. These technological devices are designed to enhance aspects of the user's life and mediate perception; changing the way the user would understand the world.

A series of design projects are proposed and created as part of a speculative platform for the investigation of the above distinctions and their implications for designers and the built environment. It is hypothesized that through the effect of Mediated Reality in Bearable Prosthesis, the dichotomy between transparency of information sharing and human privacy is collapsing to create a new form of design language, merging the user and the built environment as a result.

Keywords: Mediate, Reality, Bearability, Prosthesis, Behaviour, Environment

1. Introduction

Steve Mann coined Mediated Reality as a type of effect experienced through technological devices attached to the body, i.e. prosthesis. Such devices are used to 'deliberately diminish and more generally, or otherwise alter sensory input' [Mann, 2010]. As Mediated Reality involves a wider spectrum of senses, it creates a greater effect on the user as opposed to Augmented Reality[1].

Prosthesis is defined as a supplement or attachment to the human body [Wigley, 1991]. These may be broadly categorized into two types; 'Wearable'[2] and 'Bearable'[3]. While wearable devices are commonplace today, bearable devices are seen as the next step in user-machine interface. Bearable Prosthesis is defined in this thesis as a category of technological devices through which surveillance and intervention is facilitated by Mediated Reality. Fitted with sensors and actuators embedded within or affixed to the the body, the effect of Mediated Reality enables a localised effect.

Although Mediated Reality in Bearable Prosthesis is a relatively new systemic concept in the consumer market, the individual devices proposed within it can already be found changing the way we behave within the environment presently. The use of wireless networks in mobile devices ensure we always have a piece of technology carried with us that enable us to have access to additional information and engage in social networking while on the move. CCTVs and wireless location system ensure constant surveillance of the user by tracking his or her location in real time [Manovich, 2006]. Sensing of biodata can be seen in affordable consumers products such as the oximeter which offers the user information about their body in quantifiable measures. Embedded medical devices such as a pacemaker uses sensors to monitor the user's heart condition which suitably activates the actuators to regulate the user's heartbeat, with the purpose of life preservation. What is missing is a systemic combination of these disparate technologies.

1 Augmented Reality refers to the overlaying of dynamically changing information in the form of multimedia, enhancing user's visual field primarily [Manovich, 2006].
2 Wearable prostheses refer to computers worn under or in the clothing, or also be themselves clothes [Mann, 2013].
3 Bearable prostheses refer to implantable, portable or body-borne computers that are embedded on or in the body [Mann, 2013].

The notion of Mediated Reality In Bearable Prosthesis is introduced as a framework to question the relevance of the built environment in relation to Mediated Reality. It investigates the limit to which human behaviour can be altered with such implantable or body-borne devices during interaction with, and inhabition of the environment. The thesis also raises questions about the infringement of the user's privacy and subjective perceptions regarding the merging of our virtual and physical spaces and the ethical issue of implanting such technological devices into the body. When technology becomes invasive, questions of control between user and prosthesis will be raised. This paper argues that in the circularity exchange of information sharing between human and machine, each with their own teleological mechanisms, there will be instances where machine dominance and human subservience can occur.

The series of design projects discussed in this thesis demonstrates some of the emerging and possible consequences of the impact of Mediated Reality on users in relation to the built environment, which leads to a speculative investigation of the future of the human body with the integration of such invasive technology. Through series of experiments, prototyping and films employing topical technologies such as the multi-material 3D printer, brain wave sensing devices and Global Positioning System (GPS). It attempts to understand the various aspects of the thesis topic, i.e. (i) Materiality and its impact on the performance level of prosthetic devices, (ii) Effect of Mediated Reality on the user and the user's perception of the built environment and (iii) Perception and limits of bearability. The design projects are listed in chronological order:

1. Movement-Enhancing Prosthesis
2. Reality Mediators I
3. The Norway Experiment
4. Reality Mediators II: Limits Of Bearability
5. Bearable Prosthesis

The observations and lessons learnt from the first 4 sets of work then help build up a guideline governing the design logic of a series of Bearable Prostheses, speculated to be set in a future context where bearing such devices become common, demonstrating the potential changes in the relationship between the user and the environment in relation to such technology. As the final design work; Bearable Prosthesis, is still ongoing at the time when this thesis was submitted, hence details of it will not be shown in this paper.

2. Attachment To The Body

2.1 Notion Of Prosthesis

The relationship between a prosthesis and a user is primarily an addition or attachment to the body. In different contexts, the relationship between the prosthesis and the user varies, but bears similar understanding, i.e. prosthesis as an extension of the body to supplement its deficiency. [Wigley, 1991].

To the user's biological body, a prosthesis is used to enhance or counter a weakness. In this context, the technological side of the device imitates biology, and could be seen as a form of substitution for the deficiency. One example might be a deaf man fitted with haptic prosthesis to supplement his loss of hearing [Wiener, 1951]. Another might be a patient fitted with a prosthetic limb or a pacemaker.

In a philosophical sense, the prosthesis is part of an extended mind. As discussed by Andy Clark and David Chalmers, who sees cognitive process consisting of bodily movements and brain processes. Cognition is a process that 'does not limit itself within the physical brain or skull' [Clark and Chalmers, 1998]. He uses the term 'active externalism' [Clark and Chalmers, 1998] to describe external supplements that we use, such as language or technological tools like a pocket calculator, that contribute to bodily movements, hence making up the cognitive process. In this context, the prosthetic device and the body can then become an external coupling system that forms part of the cognitive process. Similarly as Mark Wigley discussed in the case of Sigmund Freud's perspective, who had personally experienced wearing a prosthetic jaw for a period of time [Wigley, 1991]. He sees the body as deficient and defines the mind as the site of construction of consciousness, and sees the prosthesis as similar to the natural body and its senses; extending the boundaries of the mind and aiding construction of consciousness.

In an architectural context, prosthesis is an extension, 'an auxiliary organ'[Corbusier, 1987] that supplements the gap in the main body. Le Corbusier argues that humans are born insufficient of capabilities. We do not have the natural ability to fight natural predators, withstand harsh weathers, and hunt or fight for food [Corbusier, 1987]. We tend to forget things easily and we are ashamed of our physical form. Apart from physical insufficiency, humans are also not adequately motivated in mind; we are often in favor of leisure, and not labour. We are lazy to carry out tasks that require attention and laborious concentration. Hence we acquire tools such as shelter, clothes, cabinets, food containers, computers and robots to carry out actions that we think we are sometimes incapable of doing. All these, inclusive of architecture, become a form of prosthetic extensions to our deficient body.

If we put this notion of prosthesis discussed above in relation to a technological prosthesis and its user, the relationship becomes a symbiotic one. Mark Wigley argues that both are supplement to the other's deficiency; relating it to the use of a computer mouse [Wigley, 2010]. Both the mouse and user make use of each other as a prosthetic extension to the digital system of the computer; together, both form an interface to the virtual world. Doug Engelbart, who invented the computer mouse, discussed that the best interface happens when the user's central nervous system is able to match the outer environment through his senses [Engelbart, 1962].

The technological prosthesis in this context evolve together with the body, creating a new form of behaviour, where the effect of a prosthesis goes beyond the extension of bodies at that specific time. This means that one begins to be affected by a prosthetic device before, during and after usage [Wigley, 2010]. Andy Clark and David Chalmers discuss this with regards to the requirement of a reliable coupling system to enable a prosthesis to form part of the extended cognition. " If the resource of my calculator or my Filofax are always there when i need them, then they are coupled with me as reliably as we need"[Clark and Chalmers, 1998]. In order for a prosthesis to form a seamless connection with our mind, the memory of the effect and experience of the prosthesis when worn matters more than the duration of which it was worn. When we become accustomed to the presence of a prosthesis on us, the removal of it might incur more deficiency to our body than before. In the case of a medical prosthesis, removal of it might even result in the endangering of life itself [Clark and Chalmers, 1998].

2.2 Passive/Reactive/Active Prosthesis

This chapter introduces the different types of prosthetic devices designed to augment or mediate perception. Two main types of prosthesis are discussed; passive/reactive and active prosthesis.

Passive/ Reactive Prosthesis

Passive prostheses are devices that generate a linear action, i.e. an action from the user generates a reaction. Such devices usually create a single, if not, specific set of reactions that cannot be changed over time. Hence when a user is equipped with such devices, with a few tries, he or she can begin to expect the resultant output. Reactive prostheses fall under a category of devices that is subsumed within the genre of passive prostheses, as both generates predictable linear actions and the only difference between them is the incorporation of technological actuators in reactive devices.

The features of a passive prosthesis is further illustrated in the author's work; Movement- Enhancing Prosthesis. This series of passive prosthetic devices are designed for a particular purpose; to generate as many mechanical movements from the prosthesis as possible from a singular arm movement. While the set of mechanical movements generated are predictable, the different types of materials experimented for the components making up the prosthesis produced a range of surprising mechanical movements of different quality. It is concluded that in order to create smooth and stable mechanical movements that encompass both the soft body form with the prosthesis as an exoskeletal structure on top of the body, a good combination of soft and hard materials will have to be incorporated into the prosthesis. Another key observation derived from the use of the prototypes is that because the passive system generates predictable actions, it gives the user a sense of control over the device, enabling reliable coupling[4] to form at a faster rate.

Fig 1: Finger Gloves by Rebecca Horn, 1972
References were studied: using passive prosthesis to augment human body movements in order to re-experience spatial form

(a) (b)
Fig 2 (a): Carpal Skin By Neri Oxman, 2009
Fig 2(b): Reflexive Architecture by Omar Khan, 2002
References were studied to understand application of different quality of materials

Fig 3: Author's illustration
A total of 5 prototypical prostheses were produced, made with different types of materials for its components: Hard wood bead, soft silicon sheet, multi-material 3D printed hard, and hard+soft components

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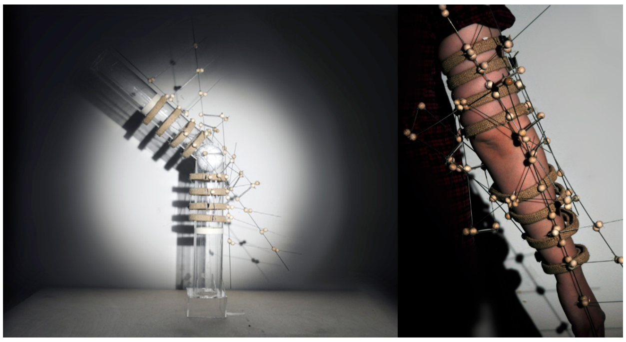
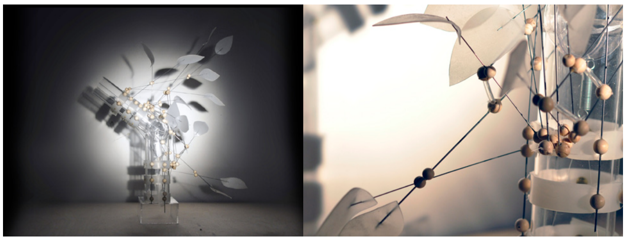
4 Andy Clark and David Chalmers discuss the requirement of a reliable coupling system to enable a prosthesis to form part of the extended cognition [Clark and Chalmers, 1998]



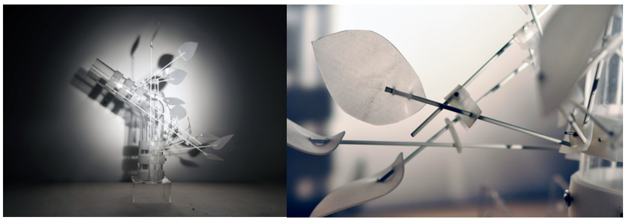
(a) (b)

Fig 4(a) and (b): Prototype 1: Hard wood beads + fishing wires +piano rods as structure
Structure is fitted on a human arm to test the quality of movement



(a) (b)

Fig 5(a) and (b): Prototype 2: Hard wood beads + fishing wires +piano rods as structure



(a) (b)

Fig 6(a) and (b): Prototype 3: Soft silicon sheets + fiber glass rods as structure

(a) (b)

Fig 7(a) and (b): Prototype 4: Multi-material 3D printed soft(rubber) with hard components + fiber glass rods as structure

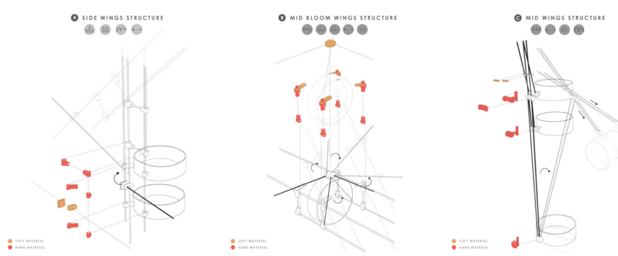
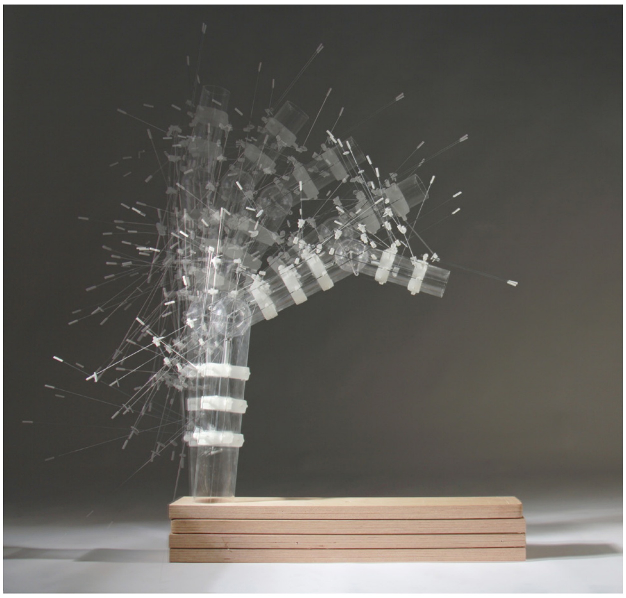


Fig 8: Prototype 5: Author's structural drawing of the various components making up the prosthesis

(a)



(b)

Fig 9(a) and (b): Prototype 5: 3D-printed hard components with manually fitted soft silicon sheets +piano rods as structure

Active Prosthesis

Active prostheses, on the other hand, are devices that generate unpredictable actions. They can be divided into two types; active goal-based and active willful. Active goal-based prostheses are mainly made up of technological sensors and actuators, and calibrated with a specific set of goals. These devices have the ability to survey the environment, record data, retain them, and based on goals, alter the degree of information to be fed back to the body through its actuators. Active willful prostheses are similar to the former in terms of the systems embedded. However, the difference is that they are more user specific and often through prolonged usage, develop its own understanding based on user's preference and makes its own decision to alter the information fed back to the user's body.

This thesis focuses on a category of active technological devices that begins to dictate our consciousness (perception and autonomy) through prolonged usage. Fitted with sensors and actuators embedded within or on the body, such localised devices can have direct and immediate impact on the body. Its extensiveness in surveying and actuating gives it the potential to take control of the user's perception, altering and changing the way the user behaves and perceives the environment based on its own set of goals.

2.3 Role of Prosthesis: From the 20th to the 21st Century

20th Century

Mark Wigley discussed with regards to the invention of the computer mouse, " A history of the 20th century prosthetics can be written in terms of the ever smaller movements of the fingers that have ever greater effects over every larger domains"[Wigley, 2010]. Human behaviour can also be seen evolving as a result of the introduction of domesticated technological appliances in the 60s. In the case of the computer mouse, through the sense of touch; movement across a horizontal surface is translated into visual movement across the virtual screen, augmenting the user's gestures. It achieves the goal of being a reliable coupling system in the user's perception and allow them to subconsciously interact with the prosthesis on a daily basis.

Our interaction with the environment has become more personalised, portable and encapsulated within a non physical layer that is seemingly attached to our body; the virtual world, which comes through in the form of computers and prosthetic devices such as our mobile phones. Our perception becomes mediated as we begin to understand the physical environment through the virtual information layered onto our natural body's senses, becoming part of our extended cognition. This notion may be seen to be expressed in the prosthetic piece created by Walter Pichler, 'Portable Living Room'. It describes a desire to be contained within our own private space with diminished contact with the real world. The artist criticised the new media's ability to induce laziness and atrophy. For Walter Pichler, it seems media is not architecture, hence he makes it architecture by physicalizing the presence of the media by including media input within this prosthesis, creating this seemingly portable piece of self contained architecture [Pichler, 1996].

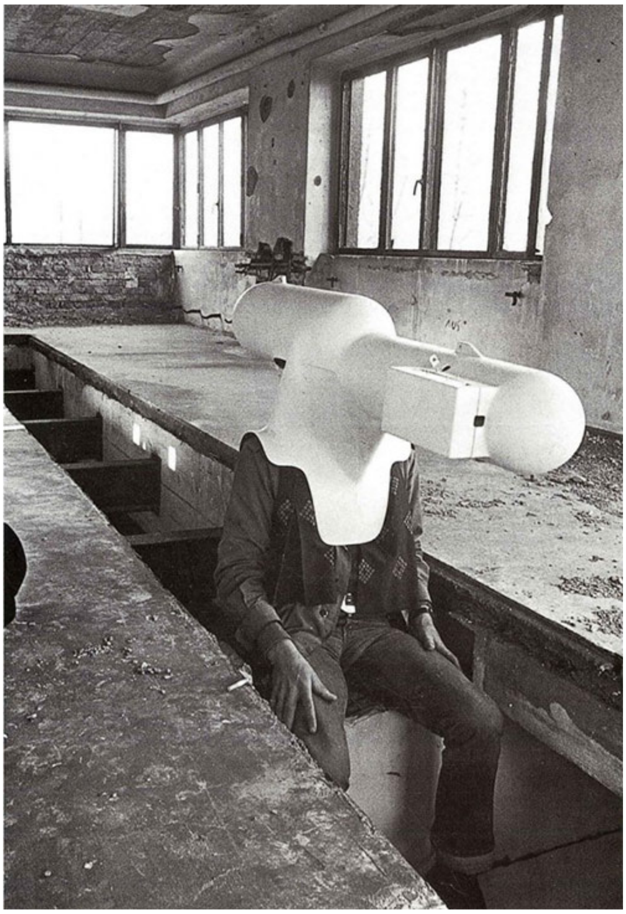


Fig 10: Portable Living Room by Walter Pichler, 1967

21st Century

Paola Antonelli discusses about the current trend in prosthesis, which involves " stronger involvement of the senses to both enhance and integrate the delivery of high-tech functions" [Antonelli, 2008]. In order to further domesticate technological prosthesis, it often involves getting the interface between user and technology to be more micro in terms of movements and fading visibility in terms of presence. Mark Wigley describes the requirement for creating a user-computer interface as "at once technological and biological"[Wigley, 2010]. It involves the alteration of our behaviour (expanding the human ecosystem) in order to communicate with the electrical circuitry and signals creating the digital world (expanding virtual environment). Through this, the user and machine can establish a common ground, enabling user and the digital space to enter each other's world. Prosthetic technology has thus becomes more intrusive and pervasive as a result.

This is evidenced from the evolution of the interface with the virtual world from the use of computer mouse to touch screen interface to gesture-controlled devices; as seen in the latest invention to hit the consumer market - Myo[5], a device that detects muscle movements and in turn enables manipulation of other connected technological devices or

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5 Myo: Gesture Controlled Armband https://www.thalmic.com/myo/

movements within the virtual gaming world. Technology used in architecture also starts to invade our privacy as evidenced by the usage of biometric technology[6] and ubiquitous computing[7]. Intelligent agents that come in the form of technological appliances constantly tracks the health,mood and safety conditions of their owners [Poslad, 2009]. Reminding and advising us when to take our pills, what to wear to work or when to exercise, augmenting our behaviour within private space. The boundary between the user's privacy and information sharing for the user's welfare continues to be blurred.

Technological prostheses also become more attached to the human body, as seen by the introduction of wearable and bearable computing devices in recent years. As defined by Steve Mann, wearable computers 'may be worn under, over, or in clothing, or may also be themselves clothes'[Mann, 2013]. He coined bearable computing as a new term that goes beyond the concept of wearable computing, so far as to 'include all manner of technology that is on or in the body' [Mann, 2013].

In addition to Steve Mann's definitions, the author would like to add on further distinctions. As wearable devices form part of the user's clothing, it may be taken off by the user any time. As it is visible to the eyes of the public, the user might succumb to differential treatment in contexts that require stringent checks or high surveillance, e.g. at airport customs, casinos, or banks. Unlike bearable devices that are body-borne and may be attached permanently to the user, their almost invisible presence[8] in the eyes of the public allows minimal discrimination. Hence, bearable devices can be seen as the next step in creating a better user-machine interface.

2.4 Future of Prosthesis As An Artificial Intelligence

To become part of a technologically advanced society, surveillance and intervention must form a symbiotic relationship with the user. Lev Manovich contextualised this with regards to the emergence of Augmented Space [Manovich, 2006] in the form of the internet, wireless location system, mobile phones and digital displays. " By tracking the users- their moods, pattern of work, focus of attention, interests, and so on- these interfaces acquire information about the users, which they then use to automatically perform the tasks for them"[Manovich, 2006].

The future of technological prosthesis can then be hypothesized to be an artificial intelligence that has its own understanding of the environment and the user. Through prolonged period of coupling with the user, it is able to learn and adapt to user's preference, and starts to dictate the user's consciousness (perception and autonomy) through the effect produced. Intelligence in this case is not an attribute possessed by the device. As discussed by Ranulph Glanville, the presence of the quality of intelligence involves an observer's interaction with and recognition to, in this case, an artificial machine [Glanville, 2001].In the context of Bearable Prosthesis, the device is deemed intelligent by the user if it is perceived to recognise the user's preference over time and create bespoke effects that the user finds pleasant.

3 Mediated Reality

Before the term Mediated Reality is discussed, the term Reality is examined through key references cited in this thesis to better understand and construct an understanding of what it means for a user to be in reality, and to be in a reality that has been mediated.

3.1 Reality

David Chalmers discusses a reality that is based on the act of being conscious, "I think, therefore I am conscious"[Chalmers, 1995]. From his viewpoint, reality is the construction of the environment by the individual's experiences, as part of the act of being conscious. In this case, consciousness is part of the cognitive process[9] . If we relate this to the formation of a reliable coupling system between the prosthesis and the user as part of the extended mind [Clark and Chalmers, 1998], when a prosthesis is fitted onto the user's body, it then has the ability to affect the user's perception of reality.

From a cybernetic point of view, Heinz Von Foerster bases the term Reality in relation to human discovery of things around them, such as language [Foerster, 2002] and these discoveries form part of the user's cognition. As he argues,"it is he (the observer) who invents it, and likewise, when we perceive the environment, it is we (the observers) who invent it" [Foerster, 2002]. The term is broken down to become an "operation of a recursive descriptions"[Foerster, 2002] in the user's mind, made possible by continuous discoveries. Hence reality is a construct of the user's cognition.

Oliver Sacks describes our body senses,such as the eyes as a tool given to us since birth, as an aid for us to construct the environment outside our body and mind [Sacks, 2011] . The information collected by our senses is fed to our brain, which helps construes our experience, forming part of our cognitive process. Our reality is then highly dependent on the information received by the body senses as it acts as an interface between the environment and our mind. Hence it can be said that our brain constructs our individual version of reality through the body senses.

While some of the other key references did not specifically define reality in their researches, they point towards similar meanings to those discussed above, i.e. reality as a construct of the user's perception, whereby perception is produced as part of the

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6 Biometric door access into buildings record and survey not only the number of people, but the personal data of the people in the building.

7 Ubiquitous computing has invaded our private space as well, as seen in smart house.

8 As devices are embedded into the body or can be concealed easily under clothes or accessories in the case of devices attached on skin

9 Cognitive process consists of bodily movements and brain processes [Clark and Chalmers, 1998]

cognitive process in the mind. This is suggested in the way they discuss about topics relevant to reality. For Steve Mann, a user experiencing Mediated Reality involves "allowing individual to communicate with one another by altering each other's perception of reality" [Mann, 2003]. This suggests that reality is perceived differently by various individuals. Doug Engelbart, who deals specifically with Virtual Reality as the the simulated space displayed by computers, speculates on a future where computer-user interface can be established directly through the user's brain, bypassing the body senses [Engelbart, 1962]. This suggests that the body senses help the mind construct perception of the environment, forming the individual's reality.

If reality is constructed by the individual's perception of the environment. Why is it that certain commodities can produce similar sets of reactions from the masses? For example, when we are presented with a computer mouse, why is it that we know this is a tool for communicating with the computer? For most of us to employ similar methodology and establishing similar relationship, i.e. to hold onto the mouse and scroll it along a surface to navigate the virtual space in the computer screen, suggest to us that our construct of reality could be the same. Why is that so?

Heinz Von Foerster argues that within our own reality, it is made up of a community of other individuals' realities, as we interact with the environment that is made up of other observers. Hence this helps establish a certain common ground among all of us, allowing us to have similar associations. He refers to " reality = community"[Foerster, 2002], suggesting that there are other individuals with their own perception of reality in the environment, and these make up a certain set of similarities between us. As he states, " If you desire to see, learn how to act" [Foerster, 2002]. It can then be said that our individual reality is made up of our perception through interacting with other individuals in the environment.

This is supported by contemporary theorists such as Lev Manovich who discusses the contemporary notion of reality as a database, where a user perceives the environment through the "world wide web filled with ever changing data, images, texts"[Manovich, 2002], contributed by users around the globe who engage with the internet. Reality is then defined by the data that the internet provides to the user, which is information created by other individuals' realities.

The definition of reality in this thesis can then be concluded to be a construct of the user's perception, which is made up of sensing the environment through the user's body senses, observations, discoveries and interactions with the many different entities constituting the environment. It therefore means that our reality can be easily influenced and altered by external input and has the potential to be mediated.

3.2 Mediated Reality | Augmented Reality

To mediate is to intervene or act as a middle agent, separating two different entities, in this context, the user and the environment. It differs from augmentation as it generally refers to amplification or intensification. Put simply, to augment is to put a transparent layer of information over the user's senses, in which the user then perceives the environment through the layer. Whereas to mediate is to put a translucent layer of information over the user's senses. As a result, the user would perceive less of the external environment and have to rely more on the information found in the translucent layer. This also means that this middle agent has the ability to convey its own desired information between the two entities, without them knowing the degree of accuracy of the raw information. Devices that create the effect of Mediated Reality is designed to act as an intervening agent between the user[10] and the environment, conveying messages between the two. Therefore it has the ability to mediate our perception of the environment around us, hence our notion of reality.

Mediated Reality[11](MR) bears similarity to Augmented Reality[12] (AR) in the sense that both are personalised tools that involve the layering of information onto the physical space which the user is in, through the body's senses. The former involves the modification of information onto more senses which could encompass visual, audio, haptic or other bodily senses [Mann, 2010], while the latter involves the layering of information onto user's visual field primarily.

The main difference between the two terms lies in the degree of control users have over their perception. An MR device modifies perception of the user based on its own set of goals which is calibrated into the device's system. Hence it has a higher degree of control over its user. Examples of such devices could be seen in medical prosthesis such as a pacemakers or in Steve Mann's Computer Reality Mediators [Mann, 2003]. While an AR device intensifies the user's experience through layering of information that would aid the user in understanding the space he or she is in, which is seen in examples such as Google Glass[13]. As such, the user has a higher degree of control over the devices since he or she can filter out the information that is provided. In addition, an MR device has the ability to survey the user's bio and personal data on a broader spectrum as it involves more senses; hence it supersedes Augmented Reality in terms of creating a more immersive experience for users.

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10 Refers to user's body senses

11 MR refers to the artificial modification of human perception by way of devices used to deliberately enhance and more generally, or otherwise, alter our senses [Mann, 2010].

12 AR refers to the overlaying of dynamically changing information in the form of multimedia, enhancing primarily, user's visual field [Manovich, 2006].

13 Google Glass is a wearable computer that function as a data provider similar to desktop computers and smartphones, developed by Google: http://www.google.com/glass/start/

Fig 11: Mind Mesh by Steve Mann, 2012
The Mind Mesh is a mesh-based computing architecture currently under development, to allow various sensors and related devices to be "plugged into the brain"

3.3 Mediated Reality and the Built Environment

Mediated Reality experienced in relation to the built environment can be referred to as 'posthuman domesticity' [Spigel, 2005], which is a term used to explore the way that everyday human experience is orchestrated by telerobotics and intelligent agents. With this paradigm shift, the way the built environment is conceived by designers, architects and users will have to evolve as well in order to embrace the new age.

In the 1990's, Robert Venturi articulated the new vision of architecture as 'communication for the Information Age'[Venturi, 1996] in relation to electronic imagery pertaining to mainly surfaces of buildings. One example that embraces this notion could be seen in Times Square, New York, where huge electronic billboards that bombard the people with flashing images twenty-four-seven, are mounted on the facades of buildings. In this case, architecture is seen as an 'iconographic representation' [Manovich, 2006] where dynamically changing visuals attach themselves to building surfaces. Lev Manovich argues that designers should not only limit themselves to the screen as a tool of augmentation, but to consider it as a volumetric approach [Manovich, 2006]. This argument is seen aligned with the notion of Mediated Reality, where architecture is perceived as a constant flow of information fed to users, not only through flat surfaces, but through the articulation of spatial flow and the choreography of experience through space, with users being controlled by the technological prostheses.

The thesis speculates that Mediated Reality calls for a new type of spatial environment that is created based on user's prolonged interaction with the Bearable Prosthesis. As the device starts to dictate the user's consciousness (perception and autonomy), the environment perceived by the user is then produced by the device. It bears similarity to the concept of ubiquitous computing, used in examples such as Smart House; in which the environment and the user can constantly interact, and together evolve with increasing interaction [Poslad, 2009]. This could potentially create a democratic city, a bottom up approach in which the built environment can become personalised for each user.

3.4 User In Mediated Reality

The effect of Mediated Reality on the user and the user's interaction with the environment are explored through the author's work; Reality Mediators I. It consists of 3 sets of design experiments that seek to explore the degree of disruptiveness created by active goal-based technological prostheses. The 3 sets of experiments consist of 3 different types of sensors, i.e. muscle sensor, brainwave sensing device and Global Positioning System (GPS). They are paired separately with 4 types of actuators, i.e. electrical muscle stimulation, sound actuators, heat pads and vibration motors, fitted onto different parts of the body. All the outputs create inherently unpleasant effect on the user so as to measure the level of obvious disruptiveness to user's everyday activities.

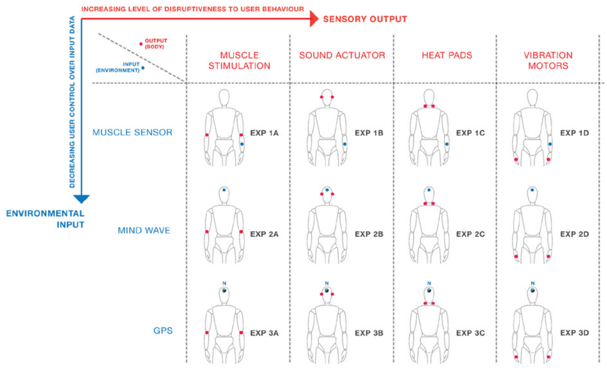

Fig 12: Reality Mediators: Author's illustration on the various experiments to be carried out

Each set of device is fitted onto the author's body for a duration of approximately 3 to 4 hours separately, to better understand the effect on human body. A few of the devices are also fitted on other users to compare the differences in experience. The observations are then recorded in the form of an anecdotal account, consisting of three key aspects to be measured:

(i) Level of disruptiveness to the user's everyday activities
(ii) Level of user awareness on own body condition and surrounding environment
(iii) Degree of comfort in wearing the devices

The design, branding and packaging of the devices are intentionally made to resemble that of consumer based products, questioning the extent to which consumers can accept such type of invasive technology that seems acceptable on the outlook, but produces disruptive effects on users. It also questions the notion of how one can be affected by a prosthetic device 'before, during and after usage'[Wigley, 2010].

Fig 13: Packaging of the devices

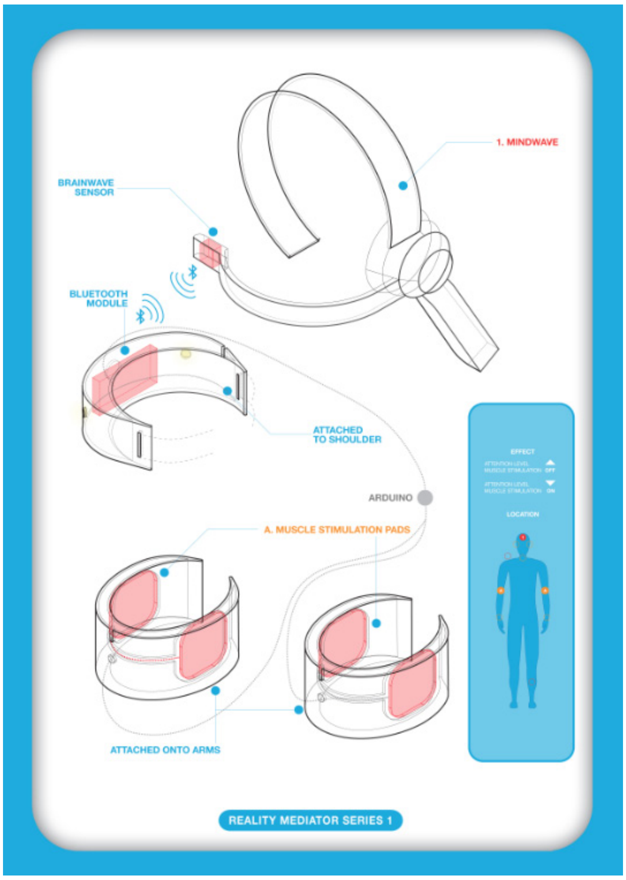

Fig 14: Author's illustration used in the brochure, created to demonstrate the method of wearing the devices and the effect to expect from wearing them

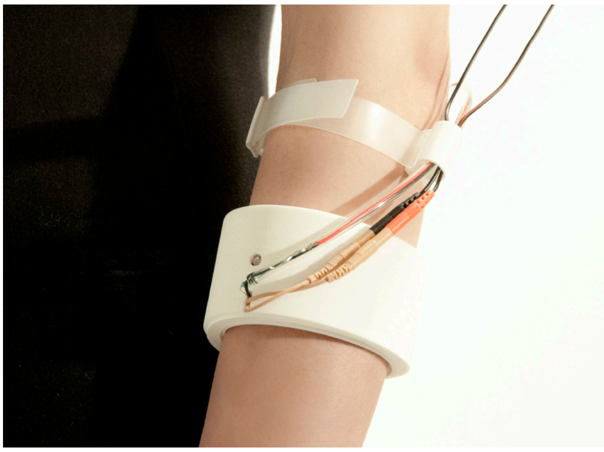

Fig 15: Muscle stimulation arm band

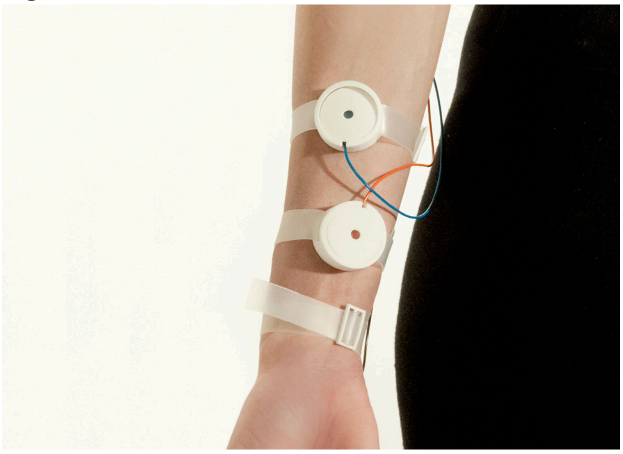

Fig 16: Muscle Sensors detecting arm muscle activities

Figure 17: Mindwave device detecting brain wave activities

Fig 18: Heat Pad on neck to induce perspiration

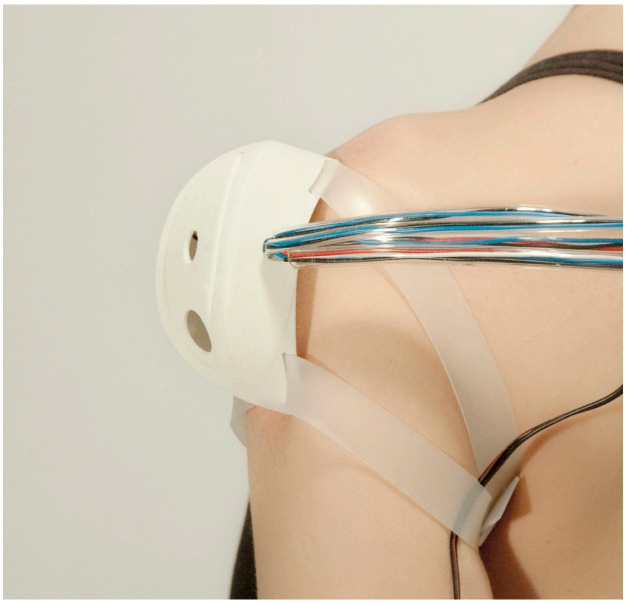

Fig 19: GPS and digital compass, locating the user's position in real time location

Fig 20: Piezo (sound actuator) fitted on back of ear

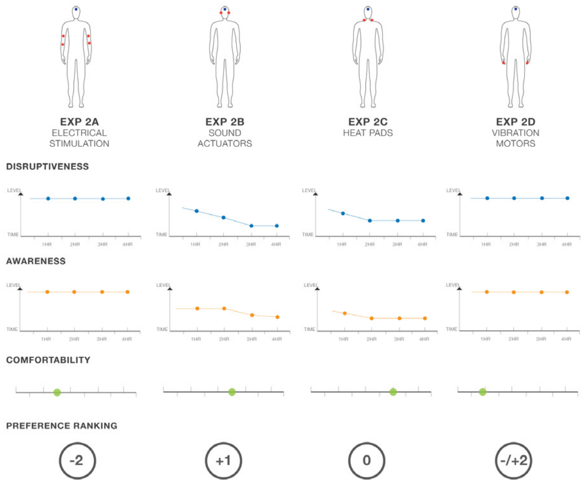

Fig 21: Author's data records
Result of Experiment Set 1: Muscle sensor as input, paired separately with the 4 different actuators

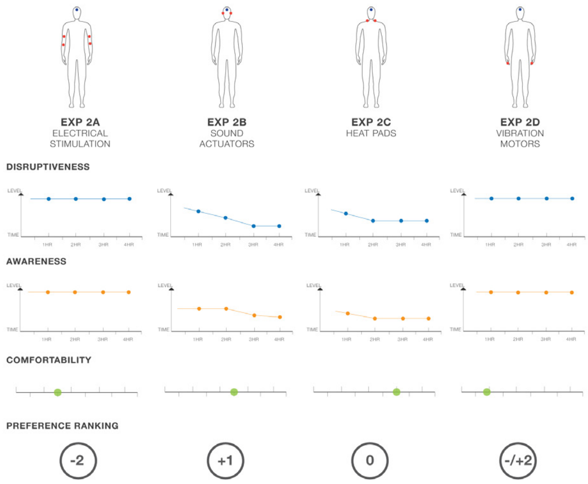

Fig 22: Author's data records
Result of Experiment Set 2: Author's data records Brainwave sensing device as input, paired separately with the 4 different actuators

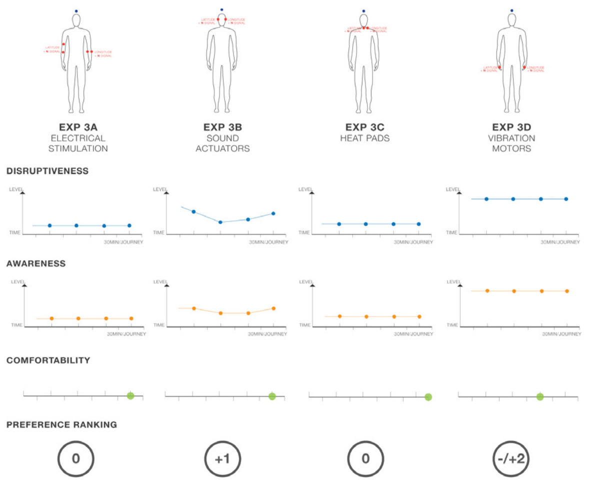

Fig 23: Author's data records
Result of Experiment Set 3: GPS+digital compass as input, paired separately with the 4 different actuators

Some main observations were recorded from the wearing of all 12 sets of devices:

1. Through prolonged usage of devices (16 hours and more), user starts to adapt to the effects, and changes activity patterns with consideration to the presence of the device.
2. The way the environment (the user's body and built environment) is perceived changes as the effect provides another layer of information on top of the body senses.
3. The effect of the device can be beneficial or detrimental, depending on the different environmental conditions and the user's preference.
4. The more the user is (i) unaware of the effect (ii) feels the sense of control over the device (iii) unaware of the presence of the device, the more comfortable the user feels.

Through the design experiments, it can be concluded that creating a reliable coupling system[14] between such technological prostheses and the user involves the choreography of the whole experience; the layering of different processes, before, during and after usage. Failing to implement one or others will cause a change in the resultant user's experience and subsequently, the changes in the way the user perceives the environment.

4 Bearability

4.1 Elasticity of the Senses

Paolo Antonelli defines the term Elasticity[15] as "the by-product of adaptability +acceleration'[Antonelli, 2008]. Elasticity is characterised by our capability to embrace fast changing advancements and capitalise them for our own purpose. Our brain develops in a way that adapts to external tools, enabling it to become part of the extended cognition. One example is seen in the sensory prosthesis created by Norbert Wiener, designed to replace loss of hearing with the sense of touch through a prosthesis that sends electrical vibration to the fingers [Wiener, 1951]. Through wearing of the prosthesis for a prolonged period of time, a deaf user is able to mentally translate the language of the electrical vibrations; rhythms and intensity, to understand what the speaker is saying.

It can be concluded that our mind can be both elastic and sensitive at the same time; to reject or accommodate changes in our environment. In the case of a Bearable Prosthesis, if reliable coupling is formed, the mind is elastic enough to adapt and make full use of the device, allowing it to become part of its extended cognition. If anything during the process causes the user to receive an unpleasant feedback, the mind is sensitive enough to reject the device. However, if the unpleasant feedback happens after prolonged duration of bearing the device, the mind then becomes uncertain whether to reject or accept it, and chances are it will accept it as the user is already dependent on the device after prolonged period of usage. Hence, what makes a prosthesis more or less bearable for the user is not so much the extent of the physical pain or durability that one has to go through to bear the device, but more of the effects it is providing on the long run.

4.2 Criteria For Bearability

Through lessons learnt in the author's works, a set of 5 criteria is derived as a guideline to be observed in the designing of the Bearable Prosthesis, with the aim of allowing users to bear it for a prolonged period of time, in this case, projected to be the whole lifespan of the user.

(I) Invisibility - Reliable coupling system

The initial physical fit on the user is important. Materials used for the device play a key role in providing a stable structure attached on or embedded into the soft body form. With a comfortable fit, the user would then be used to the presence of the device, allowing the user to fully experience the effect of the device. The effect should also be catered to the user's preference in order for user to willingly accept the bearing of such device.

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14 Andy Clark and David Chalmers discuss the requirement of a reliable coupling system to enable a prosthesis to form part of the extended cognition [Clark and Chalmers, 1998]

15 Paolo Antonelli discusses the term, Elasticity, in relation to the 2008 exhibition at MoMA, 'Design And The Elastic Mind':http://www.moma.org/interactives/exhibitions/2008/elasticmind/

(II) Sequence of system flow: Passive/ Reactive to Active (Goal-based) to Active (User-based)

It is proposed that apart from the active systems embedded within the device, having a good combination of passive/ reactive together with the active parts matters as well. As passive/reactive system generates predictable actions, usually in the form of visual movements, it helps the user to feel that he or she has control over the device, allowing reliable coupling to form at a faster rate. The active part of the system comes in two parts; goal-based and user-based. The goal-based system is a set of goals pre-calibrated into the device, while the second part; active (user-based) comes from a long duration of bearing the device, having the device slowly forming its own understanding of the user, creating bespoke or willful effects catered for the particular user.

(III) Duration

It is speculated that reliable coupling would have already been formed during the period of experiencing the effect of the passive/reactive and active goal-based components of the device. If supposedly, the experience is a pleasant one for the user, the user would then be willing to bear the device for a prolonged duration. The long term effect; the effect of the active user-based part of the device will then surface. Whether it is beneficial or harmful for the user, is purely subjective.

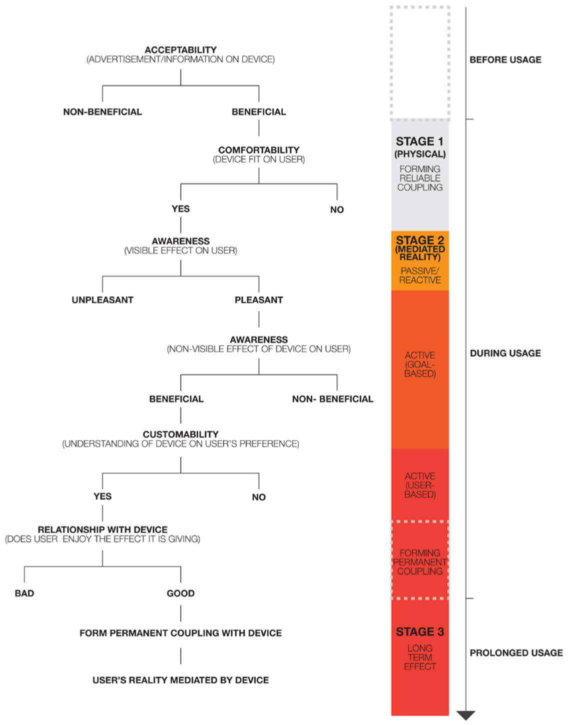

Fig 24: Author's flowchart illustrating what makes a device more bearable for a user

(IV) Belief system

Our own set of belief systems governs the way we perceive and accept extreme conditions. It plays an important role when deciding whether to embrace or reject the effects that such an invasive device will provide. As David Chalmers illustrates with the comparison of different users navigating the streets to get to a destination employing their own belief system but projected onto different items; notebook and user's stored memory [Clark and Chalmers, 1998]. The illustration shows that when a user believes that a tool can improve productivity or supplement their deficiency, a bond of dependency forms between the tool and user, creating a reliable coupling system which forms part of the extended mind. Similar to that, both a patient with a heart condition (who believes that a pacemaker will regulate his heartbeat) and an African tribe woman (who believes that the bigger the lip plate implanted into her lip, the more attractive and socially accepted she is in her tribe) will accept an external tool whose effect they perceive to be beneficial.

This can also be found in references such as Steve Mann and Stelarc. Steve Mann, who has been experimenting and recording his experiences through various Reality Mediators [Mann, 2003] that he created and worn, promotes the usage of such devices on a daily basis as an important sousveillance tool for the purpose of personal safety [Mann, Nolan and Wellman, 2003]. In the case of his Reality Mediators, the devices are able to record and store data experienced by the users; visually, audibly and biologically [Mann, 1996]. Hence acting as a form of monitor for health and social safety. This is proven by his recent assault in Paris[16], in which the police were then able to arrest the culprits because of the visual evidences recorded by his EyeTap[17] device. Ironically, the reason why he was assaulted in the first place was because of his EyeTap device, which attracted unwanted attention from his assailants. For artist like Stelarc, who has performed numerous body modification on himself, implanting both biological and technological prostheses into his body, sees the body as an 'object for designing' [Stelarc, 1997]. As he thinks that the body is obsolete in keeping up to date with information. He believes that instead of supplementing the defective body, we should recreate the human body to form a hybrid with technology, enabling our body to not only record information, but become immortal.

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16 Augmented Reality Explorer Steve Mann Assaulted At Parisian McDonald's. Retrieved from TechCrunch, 2012: http://techcrunch.com/2012/07/16/augmented-reality-explorer-steve-mann-assaulted-at-parisian-mcdonals/

17 An Eye Tap is a wearable visual device that function both as a sousveillance tool and a device that implements the effect of Augmented Reality. Created by Steve Mann [Mann, 2010].

(V) Prejudices

The perception of the users by the outside world also plays an important role in determining whether we are willing to have such invasive devices attached or implanted into ourselves permanently. One would have to be prepared to face discrimination or unfair treatment; public prejudices and unfair authoritative treatment at times. From Steve Mann's own experience, he noticed that most discrimination he faced was due to concerns with infringement of privacy. However, one interesting observation he noticed was that there were less prejudices when the form of the device looks deceptively less dangerous or looks more relatable to public or the targeted audiences. As in the case of him walking into a jewellery store with his device that looks more like a fashion accessory than a surveillance tool, he noticed that shop owner was more fascinated than intimidated by it [Mann, 2010].

As Steve Mann states,'prejudice is held because of obvious physical differences' [Mann, 2010]. Visibility affects the degree of discrimination. Comparing two types of physical defects; a person with scar or wounds on his face would have to face more prejudices from the masses as compared to a person with a pacemaker implanted into his body. Also, global and cultural influences affect how people perceive certain ideology. As in the case of Google Glass[18], although it may still be in its preliminary stage of exploration, there are already anti-cyborg groups[19] protesting and reported numbers of casinos, theatres, restaurants and bars banning the usage of such device within their premises[20].

Fig 25: Ban signage created by 'Stop The Cyborgs Org'

The Norway Experiment was created by the author as a performance-based experimental film, to elaborate upon the notion of the human body's ability to bear extreme conditions. In this case, the extreme cold and discomfort, through the use of electrical shocks. This is seen as a critical take to the notion of technology invasiveness in which our mental condition and body movements are controlled. After being publicised, the nature and quality of the film attracted both discomfort and interest from different viewers. Some of the audience members started to empathise with the actors in the film, relating themselves to the effect of discomfort on their bodies. This film not only helps illustrate the visual perception of bearability, but how the audience (external world) perceives and relate to the performers (the users of the invasive devices).

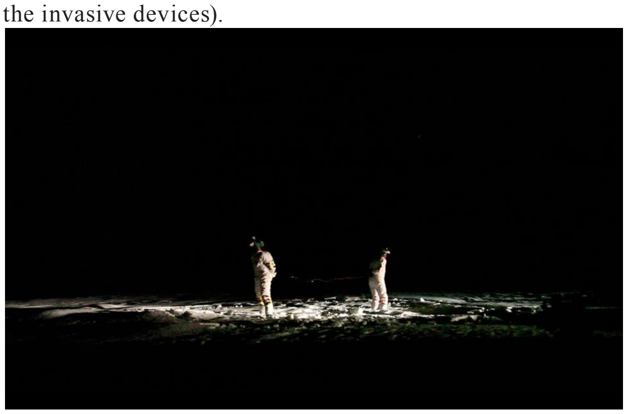

Fig 26: Still Footage from film 'The Norway Experiment'

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18 Google Glass is a wearable computer that function as a data provider similar to desktop computers and smartphones, developed by Google: http://www.google.com/glass/start/
19 Stop The Cyborgs Organisation http://stopthecyborgs.org/about/
20 Forbes 6/09/2013: Can You Really 'Ban' Google Glass? Retrieved from: http://www.forbes.com/sites/stevenrosenbaum/2013/06/09/can-you-really-ban-google-glass/

Fig 27: Still Footage from film 'The Norway Experiment'

4.3 Limits Of Bearability

The thesis hypothesizes the future of technological prostheses to be an artificial intelligence, in which through prolonged usage, begin to mediate the user's consciousness (perception and autonomy) permanently. From the author's previous sets of design experiments; Reality Mediators I, it is concluded that by wearing the devices over an extended period of time, it can alter the way the user behaves and senses the environment. Adding on to this, the next set of design experiment; Reality Mediators II: Limits Of Bearability, is designed by the author with the aim of understanding how the artificially intelligent nature of active technological prosthesis can alter the user's consciousness, and how bearable such devices are perceived by the user in the long run.

The design consists of two object-distance sensing sensors (sonic range finders) attached to the back of the neck, and two vibration motors attached separately to each side of the arm, each receiving information from one of the two sonic range finders[21]. A clock is calibrated into the device through a GPS breakout board, so that real-time data can be recorded and adjusted. The sensors and actuators are embedded under silicone sheets so that they can be pinned to clothes and be concealed easily.

Fig 28: Photograph of device setup

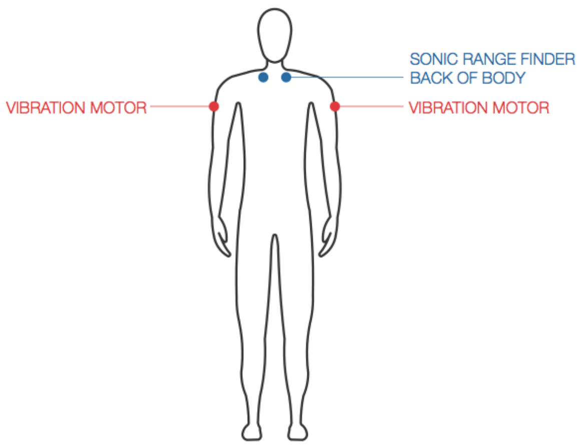

Fig 29: Author's illustration diagram on position of sensors and actuators on human body

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21 Based on the distance calibrated into the sensor, any objects (people or buildings) that is within the range of distance sensed by the sonic range finder will trigger the activation of the vibration motor, alerting the user of any incoming objects.

The author will be wearing the device for a duration of 3 to 4 weeks. During the first week, the author will manually adjust the distance sensing ranges in the coding, in accordance to her own daily activities in relation to time. After which, the code will run without any interference for a period of 3 weeks. Observations will be recorded in the form of an anecdotal account, to understand, (i) the changes in the user's daily activities after being mediated by the device (ii) how bearable the device is perceived in the long run by the user. As this set of experiment is still ongoing at the time when this thesis was submitted, results will not be shown.

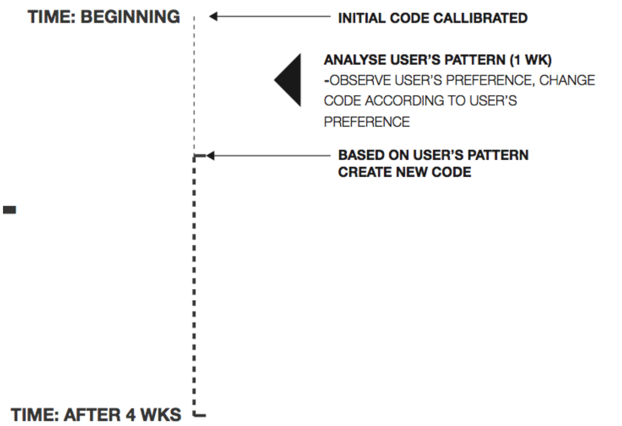

Fig 30: Author's illustration diagram on the basis of the codes calibrated into the device

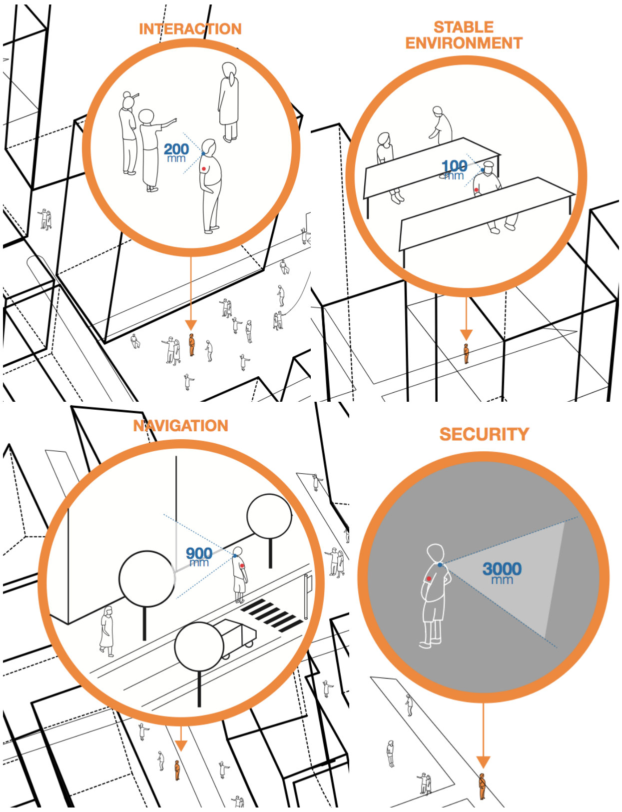

Fig 31: Author's illustration on possible scenarios showing how the user experiences different situations in the environment and how the distance sensed could be altered in relation to that

5 Mediated Reality In Bearable Prosthesis

5.1 Conclusion

While we can measure the degree to which technology transcends physical and physiological boundaries, we can only speculate the ethical consequences of these developments and their effect on human self-perception. Although such devices are still at its exploratory stage, there are already ongoing discussions and debates happening, highlighting ethical issues such as:

1. Terms Of Service (TOS)
Direct computer-brain interfaces will require new TOS, in this case who has the rights to govern or control the degree of information that can be shared between commercial companies and users[22]?
2. Hacking and Theft
As devices are directly embedded into our bodily envelope, forced removal of it from the host might endanger life.
3. Addiction to effect
Such devices are designed for users to experience the effect throughout their lifespan, any sudden malfunction might cause detrimental health effects to the user.
4. Infringement of privacy
To what degree will the users' information be exposed to companies and state, if such devices enable us to be connected to the internet twenty-four-seven[23]?
5. Governing of new territories
If such devices produce the environment we perceived, what kind of boundaries should be set and should the state, commercial companies or the users themselves govern this virtual/physical space?

In order to fully understand the impact of Bearable Prosthesis in the context where such type of devices could potentially become pervasive, apart from possible ethical consequences raised, we would also need to acknowledge the various key stakeholders involved in the whole process, i.e. the designers, architects, users, and technological companies, and for them to respond to this shift in thinking. Often the lifespans of technological devices are designed to be short-lived in nature, in order for consumers to constantly upgrade their services to enjoy comparable or new benefits, creating a stable supply and demand flow. However, in the case of Bearable Prosthesis that is embedded into the human body, designers and technological companies would have to change their strategy and project the nature of such type of devices on a long term trajectory, possibly spanning a human lifespan.

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22 An article discussing the issues raised from Brain-computer interfaces.Retrieved from http://www.kurzweilai.net/brain-computer-interfaces-inch-closer-to-mainstream-raising-questions

23 An article reporting National Security Agency (NSA) spying on users' information through the help of big corporate companies such as Microsoft. Retrieved from: http://www.dailymail.co.uk/news/article-2361372/Microsoft-helped-NSA-spy-users-e-mails-Skype-calls.html

For the users and architects, the implications of Mediated Reality in Bearable Prosthesis are far-reaching and could dramatically change the way we construct and occupy space. The notion of reality; the construction of the environment based on the individual's perception is already facing a major paradigm shift in the present context.

We no longer experience the environment through the traditional methods, such as experiencing tactility through touching the surfaces, circulating through various public and private thresholds and constructing memory of the places we have been to through our body senses. Instead, we can sometimes experience the environment through a digital reconstruction of the world without having to be physically present (Google map). Private and public boundaries are blurred on multiple levels; our private lives can often be very public (social network systems). Physical thresholds become less useful as we receive information about places we will pass by even before physically walking through it (Google glass or GPS). Instead of experiencing the environment as it is, the environment is now catered for us(Smart houses).

It can therefore be speculated that the future will continue to move towards creating technologies that can further integrate us with with the environment, attempting to merge the user and the built environment into one entity. Allowing the user's subjective perception to construct his or her own reality through interfacing with the technological devices instead of the environment itself. Given that such devices mediate our perception of the built environment and cannot be removed or stopped as it has become part of our body, there might be instances where the effect becomes unbearable for the user. Hence, there is a need for architects to respond to this, possibly by assuming multiple roles apart from designing, such as choreographing the experiences (the effect of Mediated Reality) that the user would be in and ensuring the user's physical and mental health is monitored and maintained on a healthy level in relation to the environment that the user will perceive through the device.

Issues raised in this thesis will continue to be debatable topics, which might be overlooked by users, designers and companies if we do not address it before they start integrating such invasive technology into their lives and become dependent on them permanently. As for the architects, we need to be progressive in the design of the built environment, with the understanding that the built environment is just one among many layered realities.

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Fig 1: Finger Gloves.Rebecca Horn (1972). Retrieved from http://lizzymanders.blogspot.co.uk/2012_09_01_archive.html

Fig 2(a): Carpal Skin. Neri Oxman (2009). Retrieved from http://urbanlabglobalcities.blogspot.co.uk/2011/02/carpal-skin-by-neri-oxman.html

Fig 2(b): Reflexive Architecture. Omar Khan (2002). Retrieved from http://ipoupyrev.wordpress.com/2009/04/05/chi2009-workshop/

Fig 3: Illustration graphics for Movement Enhancement Prosthesis. Ling Tan (2012)

Fig 4(a) and (b): Movement Enhancement Prosthesis prototype 1. Ling Tan (2012)

Fig 5(a) and (b): Movement Enhancement Prosthesis prototype 2. Ling Tan (2012)

Fig 6(a) and (b): Movement Enhancement Prosthesis prototype 3. Ling Tan (2012)

Fig 7(a) and (b): Movement Enhancement Prosthesis prototype 4. Ling Tan (2012)

Fig 8: Detail Drawings for Movement Enhancement Prosthesis. Ling Tan (2012)

Fig 9(a) and (b): Movement Enhancement Prosthesis prototype 5. Ling Tan (2012)

Fig 10: Portable Living Room. Walter Pichler (1967). Retrieved from http://ethel-baraona.tumblr.com/post/8093439833/walter-pichler-tv-helmet-portable-living-room

Fig 11: Mind Mesh. Steve Mann (2012). Retrieved from Mann, Steve (2013): Wearable Computing. In: Soegaard, Mads and Dam, Rikke Friis (eds.). “The Encyclopedia of Human-Computer Interaction, 2nd Ed.”. Aarhus, Denmark: The Interaction Design Foundation. Available online at http://www.interaction-design.org/encyclopedia/wearable_computing.html

Fig 12: Illustration graphics for Reality Mediators I. Ling Tan (2013)

Fig 13: Photograph of devices used in Reality Mediators I. Ling Tan (2013)

Fig 14: Illustration graphics for Reality Mediators I. Ling Tan (2013)

Fig 15: Photograph of device used in Reality Mediators I. Ling Tan (2013)

Fig 16: Photograph of device used in Reality Mediators I. Ling Tan (2013)

Fig 17: Mobile Mindwave headset. Produced by Neurosky(2011)

Fig 18: Photograph of device used in Reality Mediators I. Ling Tan (2013)

Fig 19: Photograph of device used in Reality Mediators I. Ling Tan (2013)

Fig 20: Photograph of device used in Reality Mediators I. Ling Tan (2013)

Fig 21: Illustration of results from experiment set 1 of Reality Mediators I. Ling Tan (2013)

Fig 22: Illustration of results from experiment set 2 of Reality Mediators I. Ling Tan (2013)

Fig 23: Illustration of results from experiment set 3 of Reality Mediators I. Ling Tan (2013)

Fig 24: Flow Chart illustrating the criteria required for the limits of bearability. Ling Tan (2013)

Fig 25: Graphics by Stop The Cyborgs Org. Retrieved from http://stopthecyborgs.org/about/

Fig 26: Still footage from film ‘The Norway Experiment’. Ling Tan (2013)

Fig 27: Still footage from film ‘The Norway Experiment’. Ling Tan (2013)

Fig 28: Photograph of device from Reality Mediators II: Limits Of Bearability. Ling Tan (2013)