A Usage and Motivational Model for Wearable Technology: A Users' Perspective

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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This is the thesis requirement for the degree of Doctor of Philosophy in the

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed. I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

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Abstract

Wearable technology is a rapidly growing field and can have a great impact on everyday life. It is becoming mainstream, and we need to understand how and why we use it. Wearable devices are substantially different to other mobile technologies (e.g. smartphones) and to maximise their utility we must understand what motivates people to use wearable devices, and how they are used. Due to the fact that the field is new, research into this field is scarce, and that research is generally focused on specific devices. This research takes a broader view, asking “What elements affect the adoption and usage of wearable technology?”

In this research, Twenty users of wearable technology were interviewed and a large amount of “grey literature” (non-peer-reviewed literature), such as online articles, blogs and forums about users’ experiences with wearable technology were analysed. Grounded Theory was used to create theories from the case studies provided by the interviews and grey literature.

The result of the analysis was two models, a usage model and a motivation model. The usage model showing relationships between certain aspects of the user experience (e.g. software experience) and different fields of use (e.g. medical). The model showed that the Software Experience significantly affected personal, enterprise (white collar) and wellbeing uses, but not industry or medical uses. The hardware experience only significantly affected personal and wellbeing uses. Input and Output methods affected all fields of use except Enterprise uses. It was also noted that Activity Tracking and Abandonment Decision were linked, as were Notifications with Organisation, and Notifications with Information.

The motivation model is a hierarchical model, demonstrating what motivates users to begin to use, and continue to use wearable technologies. The motivations differ significantly between the two. The model shows that fitness tracking and easy view of notifications are strong drivers to buy a wearable. Expectations and Price also have an effect. Once a user has a wearable, battery life and comfort seem to be the major factors of abandonment, along with the benefits that the user enjoys from the wearable and the value that they perceive of the wearable (in usefulness).
Additionally, a taxonomy for the classification of wearable technologies was created, based on the peer-reviewed literature. This taxonomy is instrumental in determining the parameters for the two models, as it defines what wearable technologies are. The taxonomy has six major dimensions: Primary Input and Output, Function, Aesthetics, Technology, On-body Location and Availability. These dimensions (except On-body Location and Availability) have a number of sub-dimensions. Classifying a wearable in this taxonomy allows for comparison of wearable devices and assists in distinguishing between different types.
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1. Introduction

Wearable technology is an emerging field in mobile technology. Wearable technology is technology designed to be worn by the user. Some examples of this are “smart watches” such as the new Apple Watch (Apple Inc., 2015a) and the head-mounted display of Google Glass (Google Inc., 2015b). Wearable technology encompasses many fields such as intelligent fabrics and exercise trackers (Lymberis and Paradiso, 2008, Fitbit Inc., 2015). These wearable devices and many others are becoming part of the everyday lives of many people.

Although wearable technology is a new field, the market for wearable technology is growing at a great rate. Reports estimate that 105 million wearable devices were shipped in 2018, at a value of over $19 billion (FutureSource Consulting Ltd., 2019). Another report states that $9.26 billion of the sales were smartwatches, and smartwatches sales are expected to grow to $31.07 billion by 2025 (PR Newswire, 2019).

Due to the infancy of the wearable technology field, there has been limited research done in the usability of wearable technology. The need for guidelines has been discussed (Flextronics, 2014) and basic guidelines for wearable devices have been suggested (Stack Exchange Inc., 2015), but little research has been done to create and validate guidelines for wearable devices as a whole, although some research has been done into wrist-worn wearable devices (Lowens et al., 2015).

In addition, although wearable technology shows promise in the fields of business, there is very little research done in these areas. As current research shows an increase of 8.5% in productivity and 3.5% in job satisfaction when wearable devices are used in the workplace (Rackspace, 2014) wearable devices show promise in the field of business.

In this research, wearable technology is defined as “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”. The rationale behind this definition is explained in section 2.1. “Always-on” means that the device is designed to stay on (like a mobile phone). “Peripheral interaction” means that the device can be used without requiring all of the user’s attention (similar to checking the time on a watch). “Context-aware” devices have an idea of how they are being used (e.g. not making noises when your calendar says you are in a meeting).
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The above discussion suggests that studying usability for wearable devices could assist in making wearable devices more usable, which can improve productivity and satisfaction. Wearable devices have the potential to make users more productive in their current everyday tasks for work or play.

The research question asked in this research is “What elements affect the adoption and usage of wearable technology?” The answer to this question is provided by answering three secondary questions. The answers to these questions are provided by achieving three objectives. Firstly, the current uses of wearable devices and the areas of the user experience that affect different classes of use will be determined. Secondly, the motivations that make users start and continue using wearable devices will be investigated. Finally, a number of wearable devices will be analysed and a taxonomy for wearable technology will be created, allowing wearable devices to be classified in a standardised fashion.

The understanding of the relationships between user experience and uses assists design of efficient and effective hardware and software by understanding which aspects are most important in the intended use of the device. Understanding the motivations behind adoption and continued use assist marketing of wearable devices and allow designers to design wearable devices that resist abandonment. Thirdly, a taxonomy, whilst not very useful in design, its standardised manner allows people or organisations to use this taxonomy to filter out wearable devices that do not meet their needs and compare ones that may in a standardised manner.

1.1. Motivation of the Research

The field of wearable technology is rapidly expanding and there is very little research into the user experience of wearable technology. This research attempts to explore this area to discover where wearable devices are in use, where they may be used and investigate the motivations to use wearable technologies. It should be noted that, whilst user experience includes usability, usability is not being specifically studied in this research. This is due to the fact that usability is generally device/application specific, and research into this already exists, as shown in section 2.4 (also included under the manufacturer guidelines in section 2.4.4).

Studies show that use of wearable devices is increasing, with approximately 141 million devices expected to have been sold in 2018 (Statista Inc., 2019). Wearable devices are penetrating the business environment rapidly, with a 2015 report (Salesforce.com inc., 2015) asserting that 54%
of business supported a BYOW (Bring Your Own Wearable) business model, with another 40% planning to support it in the future.

In addition, only 8% of businesses claimed that they were using wearable devices to their full extent to gain “actionable insights” from the data generated by the wearable devices. A different study in 2014 (Rackspace, 2014) deployed wearable devices in an organisation and discovered that in 3 weeks productivity increased by 7.6% and employee job satisfaction by 3.5%.

This data appears to suggest that wearable devices, whilst entering the field of business rapidly, are under-utilised with respect to their potential. The report by Rackspace (2014) shows that wearable devices can be useful to businesses and their employees. This area has not been greatly researched, and there is very little scholarly literature in the area of user experience of wearable devices. Wearable devices are substantially different to other mobile technologies (e.g. smartphones) and to maximise their utility we must understand what motivates people to use wearable devices, and how they are used.

Understanding the elements affecting the usage and motivations of wearable technology is worth researching. Understanding the usage and the motivations of adoption allow designers of wearable devices (and apps) to make the devices more appealing and useful to their users (as answered by two of the three secondary questions). The third secondary question “What are wearable technologies (wearable devices)?” allows wearables to be classified and compared in a standardised manner, allowing prospective adopters to contrast options in an informed and structured manner.

### 1.2. Current major use areas

This section discusses the major use areas for wearable technologies. Whilst there are many varied fields of use for wearable technology, it should be noted that consumer-focused wearable devices have multiple uses and could possibly become as pervasive as smartphones.

Wearable technologies have many uses. They have been used extensively in a number of fields. The sensors and ubiquity of wearable technology can be used to augment our senses (Jansson, 2015) and provide extra information as required by the user (Ostendorp et al., 2015). Wearable systems can assist their users in other ways, such as providing pain relief (Gokarneshan et al., 2015) and possibly alerting others when the wearer is in trouble (Fugini et al., 2009).
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The many varied uses of wearable devices suggest that studying the reasons people start using wearable devices, and how they continue to use them may improve productivity. The user experience when using wearable devices, why they continue to use them and the satisfaction that users derive from using wearable devices is of interest in this study.

Based on the literature review, five major fields of use for wearable devices emerged. They are Personal (section 1.2.1), Enterprise (section 1.2.2), Industry (section 1.2.3), Wellbeing (section 1.2.4), and Medical (section 1.2.5). The literature reviewed shows a large number of fields of use for wearable devices, which all may be separated into these categories. This categorisation is necessary to allow research on the different uses of wearable devices.

1.2.1. Personal

Personal use of wearable devices encompasses all fields of use not related to professional or wellbeing/medical usage. The personal uses of wearable devices are many and varied. This may be due to the multi-purpose uses afforded to wearable devices.

Common personal uses of wearable devices include mirroring of smartphone notifications and accessing simple data (e.g. weather). Navigation is also a use case that may become common, especially with augmented reality systems that are becoming available (Rudi et al., 2016, Pingel and Clarke, 2005). Users also tend to use wearable devices to express their identity (Chauhan et al., 2016).

Body area networks are also commonly used to allow multiple wearable devices to communicate, which can be especially useful in assistive technologies and in context-aware systems (Chen et al., 2011, Lymberis and Paradiso, 2008). A useful example of an assistive technology is facial recognition and facial expression recognition, especially for people who have difficulty in such areas (Abdolrahmani, 2017, Mavridou et al., 2017, Keshav et al., 2017, Kinsella et al., 2017).

1.2.2. Enterprise

Wearable devices do not appear to be greatly used in business, but they show potential in this area. Whilst research has been done on the technical aspects of wearable technology for business use (Dunne et al., 2004), there is not a great deal of research on uses for this technology. It is known, however, that the use of wearable devices in business increases both productivity and job satisfaction (Rackspace, 2014).
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Smartphones and other mobile devices require disruptive interaction (e.g. taking your phone out of your pocket, reading a SMS). This is not always desirable, and wearable technology (e.g. a smart watch) can minimise disruption by allowing the user to determine if disruptive interaction is required. Researchers in 2002 created a prototype of such a business suit (Toney et al.). Advancements in wearable technology since 2002, specifically washable electronics and conductive fabrics, would allow this suit to be used every day without any drawbacks (except possibly charging). This allows unobtrusive interaction in an enterprise environment.

1.2.3. Industry

Wearable devices can be used in manufacturing to assist in both training and production. The European Union supported the development of wearable technology through the WearIT@Work project finishing in 2008 (Lawo et al., 2008). A number of wearable devices have been developed for the construction industry, but only 2.5% of businesses are making use of them at this time (mainly due to cost concerns) (Holt et al., 2015).

As part of the WearIT@Work project (Lawo et al., 2008), a car manufacturer developed a wearable system to assist in training of manufacturing workers. The system consisted of a head-mounted display and a glove with sensors embedded in it. The system was tested but not fully deployed, and further experimentation was suggested (Maurtua et al., 2007, Stiefmeier et al., 2008).

Manufacturing workers’ training can be extensive, and they may learn skills that they do not apply until a long time after training. To assist workers, researchers developed and implemented the FAST (Factory Automation Support Technology) system. This system consists of a head-mounted display with a see-through display, a microphone and an earphone. The user may interact with the system by voice, and the system may assist the user with audio/visual information on the task that they are performing. Such a system allows the user to operate with both hands while using the system (Thompson et al., 1997, Tao, 2015).

1.2.4. Wellbeing

A major user of wearable technologies in the last few years has been the fitness and sports domain. The area of sports science has gained in popularity which has led to the incorporation of technology into this area to support and enhance benefits gained from such activities.
A number of wearable systems exist to track the exercise of their users. Arguably one of the first systems was the Nike + iPod system (Apple Inc., 2015c) where a sensor placed in a shoe connects to an iPod and allows the user to track their running.

Many exercise tracking systems now exist in the form of a wristband. The sensors in the wristband collect data about the user's movements and wirelessly synchronise with a smartphone or with a computer. A number of these also now track heart rate (Fitbit Inc., 2015, Jawbone Inc., 2015).

**1.2.5. Medical**

Wearable technology has many medical uses in various environments. In hospital, wireless telemetry (Koninklijke Philips N.V., 2014) allows ambulatory patients to move around the hospital whilst having their vital signs and location monitored in real time. As telemetry and other sensors are worn on the body, they could be considered wearable technology.

A novel medical application of wearable technology is for pain relief. A system has been developed incorporating electrodes such as in TENS (transcutaneous electrical nerve stimulation) into a garment that will allow electronic stimulation of acupuncture points that are known to relieve pain (Gokarneshan et al., 2015). Another interesting wearable developed by Google and Novoartis is a contact lens that monitors blood glucose levels (as well as correcting sight), allowing diabetics to avoid taking blood samples while still keeping their glucose levels under control (Farandos et al., 2015).

Away from medical institutions, wearable technology can also play an important role. EAMS (Electronic Activity Monitor Systems) show promise in combating obesity (Lewis et al., 2015). There are wearable alert systems for people that may need to summon help when they are away from their phone (Caremate, 2015). Another system that has been developed is a wrist-worn device that monitors multiple medical signs and can transmit them in real time to a medical centre (Anliker et al., 2004); Some smart watches could also offer a similar functionality due to their heart rate sensors (Apple Inc., 2015a). This kind of wearable devices enable potential life-saving monitoring of its wearer. Smart watches have been shown to help patients adhere to medication regimes (Shrivastava, 2015).
1.3. **What is Wearable Technology?**

The definition of wearable technology used for the purpose of this research is: “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”. This definition comes from a number of scholarly sources (Mann, 1998, Mann, 1997, Tehrani and Michael, 2014, Starner, 2001). The Oxford dictionary was also used to assist with this definition (Oxford University Press, 2015a, Oxford University Press, 2015b).

To clarify this definition, the terms may be described as follows:

- **Always-on**: Designed to be on 24 hours a day (e.g. a watch)
- **Peripheral interaction**: Not requiring the user’s full attention (e.g. SMS notification on a smartwatch)
- **Context-aware**: With at least a basic understanding of the situation of the user (e.g. alerting the user when they need to leave to arrive at a meeting on time)
- **Mobile**: Designed to be portable (e.g. wireless ECG in a hospital)
- **Easily worn or carried on the human body**: Designed to be worn (e.g. watch) or carried (e.g. smart display on a lanyard)

This definition does not include smartphones, as when a smartphone is used (with a few exceptions) it requires the full attention of the user, violating the “peripheral interaction” requirement in the definition. Virtual reality is also excluded under this requirement, although augmented reality is included, as it does not obscure the real world from the user.

The development of this definition is covered in full in section 2.1.

1.4. **Knowledge Contributions**

The aim of this research is to answer the primary question: “What elements affect the adoption and usage of wearable technology?”. This requires research into how wearable devices are used currently, which tasks they are used to support and where wearable devices may be used in the future. Further information about the contribution to knowledge may be found in section 8.3.

This research question will be answered in full with the answering of three secondary questions. The first question is “How are wearable devices currently used?”. In answering this question, the current state of wearable uses will be determined, explaining how wearable devices are currently
used (see Section 6.2). The answer to this question provides information with respect to the elements that affect the usage of wearable technology, as is part of the primary question.

The second question is “Why do users use wearable devices?”, to be answered by a deliverable explains the motivations behind the usage of wearable technologies (see Section 6.3). In contrast to the previous question, the answer to this question provides the elements that affect the adoption of wearable technology.

The third question is “What are wearable technologies (wearable devices)?”. A taxonomy will answer this question, allowing wearable devices to be classified and compared in a consistent manner (see Section 3). This allows research on wearable devices to compare similar wearable devices to other wearable devices of the same class (i.e. comparing apples to apples). This assists answering the primary question in determining what wearable technology means. The answer to this question also assists the answering of the other two questions, as they cannot be researched without a definition of what a wearable device is.

1.5. **What is User Experience?**

User Experience is a term used to mean the entirety of the interaction that the User Experiences with a device (in this case, a piece of wearable technology). This term may be taken to be distinct from usability.

ISO 9241-210 (International Standards Organisation, 2010) defines User Experience as: “person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service”. A note to this standard explains that: “User Experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use”. Usability is defined in the same standard as: “extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”.

For the purposes of this thesis, User Experience is taken to include usability, creating the following definition of User Experience (with respect to wearable technology):

“The perceptions, responses and satisfaction of wearable devices users with respect to the completion of goals with efficiency and effectiveness.”
1.6. Overview of Thesis

This thesis is divided into eight sections, which focus on the different parts of the research (and provide an introduction and conclusion).

The first section (this section) provides an introduction to the research. This section covers an overview of the research that was undertaken, providing basic knowledge in the field, along with the motivation and the aims of the research.

The second section covers the current research in the field of the thesis. The section encompasses the current wearable devices that exist, including prototypes (section 2.2). This section classifies wearable devices by their interface type, and also covers supporting technologies. The literature on the fields of use of wearable devices (section 2.2) is investigated, separating the fields of use into five categories. The usability research into wearable devices (section 2.4) is divided into wearable-specific research, mobile usability research, design process research and usability guidelines for specific wearable devices. The motivations behind the use of wearable devices (section 2.5), both before and during usage are investigated, and a section on Work-Home Interference (section 2.6) is included.

A taxonomy for wearable technologies, is explained in section 3. After an introduction to the topic (section 3.1), the section explains the methodology used in the creation of the taxonomy (section 3.2). The taxonomy is explained in section 3.3, and section 3.4 summarises the section.

Section four covers the research that was conducted and how it was conducted. Section 4.1 explains the primary and secondary research questions. The research is designed to answer these questions. The methodology behind the original research is given in section 4.2, except the methodology for the taxonomy, which is discussed in section 3.2. The theories considered in the research are discussed in section 4.3. Information about the interviews conducted is given in section 4.4 and information about the document analysis is contained in section 4.4.4. Section 4.5.3 explains the tools used to provide insights into the results and is followed by a conclusion.

The fifth section of this thesis explains the results of the research and performs some preliminary analysis. Section 5.1 explains the demographic of the participants involved in the interviews and the documents analysed. The raw data was sorted in to topics (section 5.2), which were grouped to form concepts (section 5.3) from which three themes were created (section 5.4).
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Section 6 discusses the highest-level analysis by investigating relationships and developing two models. The relationships between themes are investigated in section 6.1, providing the basis for the usage model, which is explained in section 6.2. The motivation model, which is not relationship based, is explained in section 6.3.

The research is enfolded with current scholarly literature in section 7. After section 7.1 provides an introduction, the concepts mentioned in the research are enfolded (section 7.3). The usage model is enfolded in section 7.4. Secondly, section 7.4 validates the motivation model, split into Pre-Usage (section 7.4.1) and During Usage (section 7.4.2) factors. Finally, section 7.5 validates the taxonomy and gives three examples of its use.

Section 8.5 suggests further research. After the research outcomes are stated in section 8.1, the research questions from section 4.1 are answered (section 8.2), and the contributions of the research in both theory (section 8.3.1) and practice (section 8.3.2) are enumerated. The limitations of the research and how they were or could have been overcome/mitigated are discussed in section (section 8.4). Further research is suggested in section (section 8.5) based on both the results of this research and areas that appeared to lack research discovered during the literature review process.

Finally, section 8.5.3 concludes the section and the main body of the thesis. Appendices A (section 9) and B (section 10) enumerate the devices used in the formation of the taxonomy (section 3) and a full list of topics discovered (section 5.2) respectively. The reference list for this thesis may be found in section 11.
2. Literature Review

This section encompasses the current literature with respect to wearable technology. In this section, current literature was examined to ensure that this research was original. The study of this literature was used as a basis to create a taxonomy of wearable technologies (section 3). This review of the literature is also required for the enfolding of the literature with the result of the research in section 7.

This literature was found using Google Scholar and a number of databases of scholarly sources. A number of different key phrases were used to minimise the chance of relevant material being overlooked. The literature found in this search was also used in a systematic review of the literature, leading to the creation of a taxonomy, found in section 3.

This section investigates a large amount of the literature regarding wearable technologies and aims to present it in a manner allowing the state of wearable technology research to be understood. In this section, the terms “wearable technology/technologies” and “wearable/wearable devices” are used interchangeably. To define the field of research, a definition of wearable technology is provided, created from previous attempts to describe wearable technology. Using the definition created, the current state of wearable devices (available and prototyped) is presented, grouping the wearable devices by interface type. The fields of use for the aforementioned wearable devices are then enumerated. The literature of usability (section 2.4), motivations to use wearable devices (section 2.5) and the impact wearable devices may have on work affecting home life (section 2.6) are also discussed in this section.

2.1. What is Wearable Technology?

This section explains the creation of a definition for wearable technology. As there is no agreed definition for wearable technology, a definition must be created for the purposes of this research. The definition decided upon is “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”. This definition comes from a number of papers that attempt to define wearable devices, in addition to definitions from dictionaries (Tehrani and Michael, 2014, Oxford University Press, 2015a, Oxford University Press, 2015b, Mann, 1998, Mann, 1997, Starner, 2001). Defining wearable technology is not a simple task, as different people may define wearable technology differently. For example, is a mobile phone an
example of wearable technology? When it is in a pocket it is not worn on the body, but when attached to an armband, it is worn. Another way to describe wearable technology is through its attributes.

A simple definition for wearable technology is “electronic technologies or computers that are incorporated into items of clothing and accessories that may be comfortably worn on the body” (Tehrani and Michael, 2014). Whilst this definition is clear, it does not explain the characteristics of what is commonly classed as wearable technology. A standard wristwatch is not usually classed as wearable technology, but it falls under this definition of wearable technology.

The Oxford dictionary has multiple descriptions for “wearable”. One of these is “Denoting or relating to a computer or other electronic device that is small or light enough to be worn or carried on one’s body”. The Oxford dictionary describes “technology” as “machinery and devices developed from scientific knowledge”. It should be noted that alternative definitions exist for these words (Oxford University Press, 2015a, Oxford University Press, 2015b). From these definitions, wearable technology may be described as “A machine or device developed from scientific knowledge that is small or light enough to be worn or carried on one’s body”. A simpler definition is “A computing device that can easily be worn or carried on one’s body”.

Mann (1997, 1998) attempts to define “wearable computing” in two separate papers by defining their attributes. He lists the following eight attributes to define wearable computing:

• Constant: A wearable computer must be “always ready”

• Unrestrictive: A wearable computer must allow the user to do other tasks while using it

• Unmonopolising of the user’s attention: A wearable computer should not take all the user’s attention when in use (unlike smartphones).

• Observable: A wearable computer should be able to get the user’s continuous attention if the user wants it to.

• Controllable: A wearable computer must be responsive and have a manual override of any task.

• Environment-aware: A wearable computer must be aware of its environment. This is part of the context-awareness that many systems now attempt.

• Communicative: A wearable computer must be able to communicate at all times

• Personal: A wearable computer should function as part of the wearer.
Mann (1997, Mann, 1998) also states that wearable computers should mediate by filtering information both into and out of the system. Only information that is useful to the user at the time should be displayed, and personal information should not leave the system without the express consent of the user and only when necessary. It should be noted that a number of these attributes are common to any mobile device. This definition shares a number of attributes with the definition used in this research. The constant attribute is similar to “always on”, unrestrictive and unmonopolizing relate to “peripheral interaction”, and environment-aware in this paper is the same as “context-aware”. The Controllable, Observable, and Communicative attributes are discounted, as these are common between many technologies, not just wearable technologies. The Personal attribute was dismissed due to the fact that some wearable technologies may operate independently of the wearer, which allows for ambiguity in the wearable being “part of the wearer”.

Starner (2001) mentions similar attributes, but adds that the system must “sense and model context”. It states that the system must create a model of the user’s physical and mental state, so the system can adapt its internal state to best serve the user. It also states that the system must make its model and state available to the user, so the user can explicitly tutor the system when needed. This model impresses the importance of context-awareness.

Incorporating the above descriptions provides a definition of wearable technology for the purpose of this research as “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”. Peripheral interaction can be taken to mean that the device does not restrict or monopolise the user’s attention.

Another class of devices excluded by this definition are virtual reality devices. Virtual reality is excluded because the device requires all of the user’s attention by immersing them in a virtual world. Virtual reality is a separate field to wearable technology by this definition. It should be noted that augmented reality does fall under the definition of wearable technology, because the user can interact peripherally with it, while remaining fully aware of their environment.

Non-human wearable devices, such as bovine monitoring devices (Pretz, 2016), are also excluded from this definition. The definition includes “one’s body”, which presumes that the wearer is sentient (i.e. human). Insertable technology (Heffernan et al., 2016, Li et al., 2017b, Masters and Michael, 2005) is also not classified as wearable technology, as it is inside the body which is not “worn or carried”.

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2.2. **Wearable devices**

This section investigates the types of wearable devices that exist. This section attempts to enumerate the wearable devices that exist and are in development, without regard to their uses. The wearable devices have been categorised by their interface types in an attempt to group common types of wearable devices together, as there are many various types of wearable devices.

One paper classifies head mounted displays into five categories, Low-End VR (Virtual Reality), Mobile VR, Full-Feature VR, Smart Glasses, and Next-Generation AR/MR (Augmented Reality/Mixed Reality) (Esser and Oppermann, 2016). A similar taxonomy exists for classification of hand-mounted wearable devices (Pacchierotti et al., 2017). As these classifications are related to specific types of wearable devices, they are not suitable for a full review of wearable devices. For this reason, an interface-based classification system has been created.

The two major types of interfaces are visual interfaces, such as smart watches (section 2.2.1) and audio interfaces, such as speech recognition (section 2.2.2). A number of other interface types also exist, such as haptic interfaces (section 2.2.3), augmented reality (section 2.2.4), smart clothing (section 2.2.5) amongst others (section 2.2.6). The power issues with respect to wearable devices are discussed in section 2.2.7.

### 2.2.1. Visual Interfaces

This section discusses wearable devices where their main interface is visual, excluding augmented reality systems (covered in Section 2.2.4). The most common interfaces (touch-screen) interfaces are discussed first, then some of the more uncommon visual interfaces are investigated.

Visual interfaces are a common interface type for wearable technology, as is the case in mobile technology. There are two major visual interface types in wearable technology. These are screen displays (such as Samsung Gear (Samsung, 2015)) and head-mounted displays (such as Google Glass (Google Inc., 2015b)). Head mounted-displays are very commonly used for augmented reality systems and are covered in section 2.2.4.
A large amount of research into visual interfaces (non-wearable) has been done, and a significant proportion of it has been applied to wearables. Wearable interfaces require a slightly different interaction paradigm, but some of the common rules still apply.

Neilsen (1995) provides 10 heuristics for use in visual interface design. Shneiderman et al (2010) also provides guidance with the design of effective and efficient visual interfaces. The heuristics/golden rules are shown below in Table 1, which show where they overlap and where certain principles are unique to one or the other.

<table>
<thead>
<tr>
<th>Neilsen’s Heuristics</th>
<th>Schneiderman’s Golden Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Nielsen, 1995)</td>
<td>(Schneiderman, 2006)</td>
</tr>
<tr>
<td>Visibility of system status</td>
<td></td>
</tr>
<tr>
<td>Match between system and real world</td>
<td></td>
</tr>
<tr>
<td>User control and freedom</td>
<td>Support internal locus of control</td>
</tr>
<tr>
<td>Consistency and standards</td>
<td>Strive for consistency</td>
</tr>
<tr>
<td>Error prevention</td>
<td>Permit easy reversal of actions</td>
</tr>
<tr>
<td>Recognition rather than recall</td>
<td>Reduce short term memory load</td>
</tr>
<tr>
<td>Flexibility and efficiency of use</td>
<td>Enable frequent users to use shortcuts</td>
</tr>
<tr>
<td>Aesthetic and minimalist design</td>
<td></td>
</tr>
<tr>
<td>Help users recognise, diagnose and recover from errors</td>
<td>Offer simple error handling</td>
</tr>
<tr>
<td>Help and Documentation</td>
<td>Offer informative feedback</td>
</tr>
<tr>
<td></td>
<td>Design dialog to yield closure</td>
</tr>
</tbody>
</table>

Table 1 - Neilsen's Heuristics and Schneiderman's Golden Rules

Screen displays are common, but have issues with power consumption and usability (Hutterer et al., 2005). Kärkkäinen and Laarni (2002) provide eight useful guidelines specific to small screen
web design, which is useful in this research as many wearable devices have small screens. The guidelines, as shown in Table 2, may be applied to any small screen interface (web or otherwise).

<table>
<thead>
<tr>
<th>Kärkkäinen and Laarni’s Small Screen Web Guidelines (Kärkkäinen and Laarni, 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine the purpose of the site/service</td>
</tr>
<tr>
<td>Re-evaluate the interface metaphors</td>
</tr>
<tr>
<td>Present the most important information first at the top of the hierarchy</td>
</tr>
<tr>
<td>Re-think the navigation aids</td>
</tr>
<tr>
<td>Indicate the links clearly</td>
</tr>
<tr>
<td>Optimise the reading process</td>
</tr>
<tr>
<td>Use markers when scrolling or paging text</td>
</tr>
<tr>
<td>Use pictures with caution</td>
</tr>
</tbody>
</table>

One small study showed that 83.3% of users experienced issues when checking and reading messages on small screen devices (Han and Luximon, 2016). The small size of screens on many wearable devices can cause input issues. One system attempts to circumvent the issue of a screen by projecting onto the users palm when they place their hand in front of them on a head-mounted display (Tamaki et al., 2010).

Simple touch interfaces are common, but other interesting methods have been prototyped. Generally, touch interfaces have issues that should be addressed in the design (Mortimer and Elliott, 2018). One study attempted to address this by adding the ability to tilt, pan, twist and click (depress) the screen of a smart watch. Testing proved this system to greatly increase efficiency of use (Xiao et al., 2014). It has also been suggested that the amount of pressure on a screen could be used to add another dimension to input from the user (Dempsey et al., 2015). Another paper proposed that a wrist-mounted system be composed of multiple touch-sensitive screens (akin to a segmented bracelet), although this system was not prototyped (Lyons et al., 2015).
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2012). The addition of a physical scroll wheel on the side of the watch (similar to the dial used to set analog watches) has been tested in studies, and is implemented in the Apple Watch as a complement to a touch screen interface (Raghunath and Narayanaswami, 2002, Apple Inc., 2015a). Whilst screen displays may be the most common type of visual interface, they are not the only way for a user and system to interact on a visual level.

To avoid the issue of touch screens, one suggested method of input uses ambient light, where the user may input to the device by placing a finger over the light sensor (Yoon et al., 2016). An interesting system uses changes in ambient light to determine touchless interaction on a device such as shading screen with one’s hand (Kaholokula).

In summary, visual interfaces are usually composed of a screen (often with touch capability) or a head mounted display. Alternatives to touch have been examined which involve movement of the screen, pressure levels placed on the screen, multiple touch sensitive screens, or use of ambient light to replace touch input. The main guidelines for usability of such interfaces are similar to standard usability principles but require designers to compensate for the small size of the screen and the inability for precise interaction.

### 2.2.2. Audio Interfaces

In this section, wearable devices that are primarily using an audio interface are discussed. Speech recognition is covered first, as it is the most common method of input. Other methods of input for audio-based systems are then discussed.

A number of tasks that people perform require unrestricted vision (e.g. driving). This means that visual interfaces, with the possible exception of augmented reality, are not optimal in these circumstances. Some systems have been developed that use audio as their primary interface method, leaving the user's eyes free.

Whilst audio output is simple, speech recognition as a form of audio input still faces challenges. One paper experiments with different microphone placements to avoid the user wearing a headset. It also notes that interaction with other systems is important to allow context to be determined (Sawhney and Schmandt, 1998). Another paper aims to detect the activities of the user by a chest-mounted microphone. The system proved to be 72% accurate with over 5 activities (Yatani and Truong, 2012). This allows context to be discovered, in turn leading to better speech recognition and a more reliable audio interface.
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To avoid speech recognition entirely, a different form of input for audio systems has been developed using eyes-free gestures. A paper suggests that a set of headphones could produce the impression of a “ring” of different audio objects around the user (e.g. a phone call could have a ringing noise). The user can make gestures on a device screen to interact with the “ring” (rotate and select). The user does not need to see the screen that they make gestures on, as the feedback is entirely audio-based (Brewster et al., 2003, Lumsden and Brewster, 2003). A hybrid approach has been developed where a head-mounted display is used to allow the user to see an outline of an object they “draw” around using their index finger (in the style of augmented reality). The system then tells them about the object (e.g. a landmark) (Keaton et al., 2005). These interface mechanisms do not rely on speech-based input, allowing a more accurate input method for audio-based systems.

In essence, the majority of audio-based systems use speech recognition even though it is still not very reliable. Other systems use audio output systems but use gestures as an input, to avoid requiring speech recognition.

2.2.3. Haptics

Haptic input and output is input and output using the sensation of touch. Although many wearable devices can vibrate to alert the user, this section only investigates systems where haptic input/output is a significant feature of their interaction with the user.

One ring wearable has six different vibrations, which users can distinguish between with a high level of accuracy (Han et al., 2017). Another interesting system uses haptic feedback on a sleeve over a finger to help navigate a user (Surale, 2015). The “haptic sandwich” device (Spiers et al., 2015) is another example of haptic navigation. The upper half of this handheld device can rotate and transpose to provide directional feedback to the user. It has been suggested as a navigation aid that does not require sight.

The vibration feature of mobile phones has been used to provide haptic feedback when using an on-screen keyboard to simulate the tactile experience of a physical keyboard. It has been shown to significantly improve accuracy and speed when typing (Hoggan et al., 2008).

To sum up, mobile phones have used vibrations for a long time, but wearable devices are now using more complex vibrations to confer information to the user, and some wearable devices
even change shape to provide information to the user. Haptic input does not seem to be used much yet.

2.2.4. **Augmented Reality**

This section covers systems that use augmented reality as their main interface type. Augmented reality is when the real world is augmented (in the manner of an overlay). Unlike virtual reality, augmented reality does not block out the world surrounding the user. All augmented reality system investigated used head-mounted displays (HMDs). This section discusses basic HMDs, then continues to investigate certain prototype systems.

Augmented reality is an emerging field, with few devices available for the general public. However, many prototypes have been created and augmented reality is undoubtedly a new way of interacting with a user (Microsoft Inc., 2015b).

Head-mounted displays (HMDs) are the most common form of augmented reality. As HMDs are always in the user’s field of vision, they allow hands-free interaction. While HMDs can be useful, they have a number of issues. Head-mounted systems can be extremely lightweight although they are still not considered suitable for everyday wear (Peternier et al., 2006, Tamaki et al., 2010). Although HMDs can provide an alternative to screen displays, they do still have a number of issues, such as overloading the user with too much information, one study recommends a “fisheye” tiled interface to avoid “crowding” the user’s field of vision (Belkacem et al., 2016).

HMDs have many uses. One system uses a HMD which uses a head-mounted camera to identify objects and note their location. Once the user asks the system to locate an object, the display shows a map or a photo of the last place the object was seen and direction to the object (depending on distance from the object) (Funk et al., 2014). Augmented reality, where an image is overlaid on the real world is a common feature of HMDs (and is used in Google Glass (Google Inc., 2015b)). One system allows the user to interact with virtual objects, where the HMD camera follows the user’s hands and moves the virtual objects accordingly. This allows the user to interact with the system while seeing the real world around them at the same time. This was also shown to increase the interaction speed (Plouznikoff et al., 2007). These uses of HMDs show that they have the ability to be a useful method of visual interaction between a user and a system.
To sum up, augmented reality (AR) is still an emerging field. The most common form of AR is in head mounted displays, which have an exceptionally wide variety of potential uses from locating missing items to improving interactions with both virtual and real-world objects.

### 2.2.5. Clothing

In this section, input and output methods that are built-in to clothing are investigated. This section starts by discussing the prototypes of smart clothes that exist, then explains how smart clothes also may be used as assistive technology. This section then discusses smart accessories (e.g. gloves, hair extensions) and finally discusses some of the technologies that may be used in smart clothing.

Smart clothes have been mentioned many times in science fiction, but prototypes exist. In addition, the Commuter Trucker jacket, a project by Google’s Project Jacquard and Levi’s, is a smart jacket that is now available to consumers (Google Inc., 2018b).

Many prototypes exist which gather data such as biofeedback from smart clothing (Amft, 2016, Lorentzen et al., 2016), and this is common in fitness wearable devices.

A large number of smart clothes have been prototyped (Fitri, 2017, Greinke et al., 2016, Paiva et al., 2016, Google Inc., 2018b). Adaptive garments prototyped include a shirt that allows watchers of a sports match to feel what is happening to a player (amongst other uses), and a garment that may adapt to suit the wearer (Kavitha and Suganthi, ten Bhomer et al., 2016, McGregor et al., 2016). Similarly, a dress has been developed that can adapt for different contexts (or wearers) (Lee et al., 2016). Google’s Project Jacquard and Levi’s have created a smart jacket that is already available to consumers (Google Inc., 2018b).

A number of wearable technologies can be hidden, and hidden technology can require new methods of interaction. One paper has investigated placing a wearable computer into a wig. The wig can make a camera unobtrusive and can provide haptic feedback in addition to audio (through earphones). This technology could also be implemented in a hat (Tobita and Kuzi, 2012).

Smart clothing allows for interesting ways to assist the wearer. (Baharom et al.) developed an automated zipper designed to assist people who have trouble with zips (or wear clothes with inaccessible zips). In a less trivial example, sensors were incorporated into gloves, allowing the user to gesture in sign language and have the gloves interpret the signs. The system then
displayed/spoke what the user was signing (Praveen et al., 2014). In addition to accelerometer-based detection, strain sensors have been developed to be integrated into garments (or even printed using conductive ink) which allow movement and strain on materials to be detected as an input (Farooq and Sazonov, 2015).

A similar system to the sign-language interpreting gloves could be used for gesture-based computing. Gesture-based computing has also been investigated using multiple-camera systems (Carvalho et al., 2017).

Conductive gloves are already available to allow users to interact with touch-screen devices while wearing gloves, and smart gloves have been prototyped (Koo and Janigo, 2016, Sánchez et al., 2016, Kim et al., 2016b).

Whilst not technically clothing, some smart beauty products exist. Conductive hair extensions acting as capacitive touch sensors for input are one example, as are false fingernails with NFC chips implanted in them (Vega et al., 2015, Vega and Fuks, 2013, Vega and Fuks, 2016). This technology could also be used to interface with screens in circumstances where touch is not feasible (e.g. underwater).

Smart accessories also exist (Fortmann et al., 2016, Zhang et al.) (Vega and Fuks, 2013). One study investigated jewellery (e.g. ring interfaces, speakers in earrings) (Miner et al., 2001). A notification system based in a ring is now available on the market (Ringly Inc., 2015). It has even been suggested (and prototyped) that some interfaces could be mounted directly onto skin in the form of makeup and the like (Liu et al., 2016).

Quite apart from interfaces, it has been suggested that some clothes could perform technological functions to support other wearable technologies. One study suggested (but did not prototype) a garment designed from blended textiles to act, in essence, as an antenna, greatly increasing the transmission range of wearable devices physically connected to it (Fasel et al., 2017). Smaller wearable antennas have been tested for safety, and the amount of electromagnetic radiation absorbed by the body is compliant with international regulations (Karthik and Rama Rao, 2017). It has also been suggested that RFID tags could be used for both on-body and off-body links (Manzari et al., 2011).

RFID tags have also been suggested as a means of implicit interaction (Schmidt et al., 2000). For example, a user could reach for a door handle and the RFID tag in the handle and in the user’s
sleeve would interact to unlock the door. NFC (Near Field Communication) is a new type of interface, where the user just needs to bring 2 items containing NFC chips close to each other.

Amorphous photovoltaic cells may be combined with polyester fabric to create flexible solar cells which allow for wearable power sources (Mather and Wilson, 2017). It should be noted that conductive fabrics do have higher rates of crosstalk (interference from other sources) when compared to traditional electronic circuits (Fernández García et al., 2016).

In summary, smart clothes are beginning to become available, but are not mainstream. There are a number of input methods for smart clothes (including smart accessories) and some garments can adapt and provide output to the user. A number of prototypes also exist which assist other devices in a technical manner (e.g. RFID connection, solar charging, antennas).

2.2.6. Other Interfaces

Those interfaces that are not covered in other sections are in this section. There is little research into these systems, but they are worth noting. Capacitive touch, brain-computer and accelerometer-based interfaces are covered in this section.

One paper suggests using capacitive touch for an input system, where a grounded object (e.g. a human) interferes with an electric field. A number of systems were suggested, and some basic design suggestions were proposed (Holleis et al., 2008). These interface methods are different to purely audio/visual methods and can be tailored to fit a number of wearable devices.

Brain-computer interfaces are in their infancy, but research is being conducted. A multi-sensor system including electroencephalographic measurements (brain waves) was used to control an electric wheelchair successfully, and a separate study used a similar system to control a robotic arm (Kucukyildiz et al., 2017, Minati et al., 2017, Topić and Russo, 2016). Interestingly, a study implanted sensors into a pair of spectacles to allow the detection of the wearers emotional state (Saadatzi et al.).

Accelerometers have also been used in a wrist-mounted wearable to allow authentication with accuracy of over 95%, and false-positives of under 4% (Liang et al., 2017).

In conclusion, capacitive-touch, brain-based and accelerometer-based interfaces show promise but are in their infancy.
2.2.7. **Supporting Technologies**

A significant amount of research has been done into technologies that support all wearable devices. These technologies are important but are not specific to any individual interface type.

Power is a significant issue for wearable devices. All wearable devices require power, and many use a battery for this power. This section begins with covering the methods by which wearable devices may reduce their power usage, and then explains a number of ways by which wearable devices may generate their own power, while in use.

A number of power-saving strategies have been developed (Hooshmand et al., 2017, Freeman, 2016, Khalifa et al., 2016). One such strategy increases battery life up to four-fold, due to an adaptive wireless strategy (Magno et al., 2016b). One device uses ultra-low-power systems with specialised software, giving battery life in the manner of weeks or possibly months (Hester et al., 2016). A similar system proposes using multiple ultra-low power sensors to determine context, combined with energy harvesting to create an energy-neutral smart watch (Magno et al., 2016a).

Power consumption can be a significant issue with HMDs (head-mounted-displays). Many features of HMDs require the use of a video camera (e.g. augmented reality, face recognition). Generally, video frame analysis is power-intensive and computationally expensive. To combat this, other low-power sensors can be used to determine the context that the user is operating in, and discard frames that do not require processing. A face-detection system managed to discard 70% of frames, while missing only 10% of relevant frames (Han et al., 2014). Power saving measures can be used to increase the battery life of a HMD, but they still need to be charged regularly, which is an issue for wearable technology (as it cannot usually be worn while charging).

Many other sources for powering wearable devices have been investigated, often but not always, focusing on kinetic generation (Roundy et al., 2004, Kim et al., 2015, Wu et al., 2012, Thielen et al., Sun et al., 2011, Magno et al., Hamid and Yuce, Khalifa et al., 2016, Khaligh et al., 2010) (Magno et al., 2016c). One such system, integrated into a backpack, harvests energy from the hip displacement created by the wearer walking. It was suggested in the study that it could be used by soldiers to generate power while moving (Mullen, 2017). A very interesting study looks at nonwoven nanofibers in clothing that can generate a significant amount of energy from acoustic noise (Lang et al., 2017). Flexible solar cells allow the possibility of power being generated from clothing (Hwang, 2014, Simões and Neto, 2016, Mather and Wilson, 2017).
In summary, power is a significant issue for wearable devices (especially head-mounted displays) and many issues have been made to address it. A number of low-power systems and algorithms have been proposed, as have systems that generate power while the wearable is worn.

### 2.3. Use of wearable devices

The uses of wearable devices are discussed in this section. There are a large number of fields of use for wearable devices. To make this section more understandable, the fields of use for wearable devices have been divided into five areas.

Personal uses encompass uses that are not related to the health or occupation of the user, such as weather notifications and smart home control. Business and Industry uses cover wearable uses in an occupational context in both “white-collar” and “blue-collar” occupations, respectively. The final two areas are Wellbeing and Medical. Wellbeing encompasses health uses in a non-medical context (e.g. fitness tracking), whereas Medical uses includes all health uses in a medical context (e.g. smart glasses in operating theatres, smart dressings).

#### 2.3.1. Personal

In this section, personal uses of wearable devices are discussed. For the purposes of this section, personal use is any use not related to professional or health usage. The personal uses of wearable devices are many and varied. This may be due to the multi-purpose uses afforded to wearable devices. The uses for physical and mental wellbeing are so extensive that they are in their own section (section 2.3.4).

Many wearable devices connect to other devices in Body Area Networks, small networks which are local to the user, and these networks may connect to other networks, which supports the Internet of Things. Other wearable devices may provide assistive technologies to assist users with disabilities. Augmented reality is an emerging field, which has many uses. Common uses include face recognition and navigation. Finally, this section mentions emotionally sensitive computing, which is more useful in wearable devices as they generally contain sensors on the body that allow emotions to be detected.

Body Area Networks is the term used to describe networks that are smaller than LANs (local area networks). They tend to be comprised of a number of sensor/devices that connect within a short distance (such as an area the size of a person) and can be used to collect biofeedback (such as heart rate for health monitoring). They also allow context to be determined more effectively.
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(due to the volume of data from multiple sensors) (Chen et al., 2011, Lymberis and Paradiso, 2008). Wearable devices incorporating multiple sensors have been made using the Lilypad Arduino microcontroller (Buechley and Eisenberg, 2008).

Homes can now have a number of “smart devices” that can be controlled by mobile or wearable technology (Noury et al., 2011). Body-based sensors could link to other systems allowing context-aware smart device control (Kim et al., 2016b). A wrist-based system (akin to a wristwatch) was developed to allow a resident to control devices within the home (Russis et al., 2013).

Wearable devices can be very useful as assistive technology. Different methods of feedback can be useful when users have some senses impaired (Palathingal, 2016). Facial recognition systems have also suggested to aid blind people in social interaction (Abdolrahmani, 2017). Another system has been tested that can recognise facial expressions, which may also be useful in social settings or for people who have trouble recognising expressions (Mavridou et al., 2017, Keshav et al., 2017, Kinsella et al., 2017). Inversely, another system allows people who have lost the ability to show expression to demonstrate emoticons which allow the context of their speech to be understood (Vujic et al., 2016). Some prototype wearable devices allow sign language to be automatically interpreted (Savur, 2015, Paudyal et al., 2017, Taylor, 2016).

Augmented reality has many possible applications, and research has been done on its possible uses, but they have not yet been deployed to a general population (Baktash et al., 2016). Interestingly, it has been shown that augmented reality system improve spatial cognition when compared to GPS hand-held systems (Platosh, 2017). One study developed a HMD (head-mounted display) system that recognises the face of the person the user is looking at, and provides their name to the user within 900ms (the suggested maximum socially acceptable time). It was suggested that the system could use location and social media data to narrow down the subset of faces to check for a match (Utsumi et al., 2013). One paper warns that augmented reality may also cause some problems: “AR offers great opportunities as an educational platform but also has the potential [to] manipulate people and detach them from mainstream society” (McIntyre, 2016).

It has also been suggested that wearable devices (especially augmented reality) could be used productively when the wearer is a tourist, but if other infrastructure does not exist, the wearable can be a liability rather than an asset (Rincon et al., 2017). A different study suggests that
wearable devices are useful to tourists when they are inobtrusive and are viewed as an extension of the tourist’s body (Jung and tom Dieck, 2017). It may be considered that the two conclusions of these studies are similar but differ in the way the findings are expressed.

Navigation via augmented reality systems could be used to great benefit in this context, and studies have produced prototypes of such systems (Rudi et al., 2016, Pingel and Clarke, 2005). One paper suggests that location-based augmented reality causes different behaviour in groups of people, and this can present both problems and opportunities in disaster relief (Luczak-Roesch, 2017).

In a similar vein, gamification of augmented reality has been tested in a learning environment (e.g. a museum) and a game-based simulation first improved learning over a non-game-based simulation first (Oh et al., 2017). Similar results were shown in a study where students were taught about wildlife conservation (Phipps et al., 2016). Augmented reality has also been used in museums, allowing visitors to experience 3-dimensional interactive holograms (Pedersen et al., 2017).

People have emotions, and some efforts have been made to allow for computers to sense the emotions of their user. To join the ideas of wearable devices and emotionally sensitive computing, one paper looks at clothing that embodies the user’s mood at the time. The concept of dynamic materials that can lengthen and shorten is suggested. Jewellery/undergarments were suggested as sensors that can detect the user’s mood. No prototypes of dynamic fabrics were made (Uğur et al., 2011).

Another wearable and emotionally based system consisted of patches on a shirt. Each patch corresponded to a Facebook friend. When a patch was tapped, the corresponding friend’s patch illuminated and heated slightly, to simulate human touch (He and Schiphorst, 2009). Tactile feedback provides an experience only possible by incorporating technology into clothing. This communication at a multi-sensory level allows for a more “real” form of virtual presence.

A study by Duus (2017) warns that dependence on technology (not necessarily wearable devices) may have a detrimental impact on human autonomy, by having the technology make judgments instead of the user. This may be especially relevant for wearable devices as wearable devices are generally context aware and may be expected to know when the user requires certain information (e.g. when to leave for an appointment).
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Interestingly, it was shown that 41% and 30% of early Android Wear and Samsung Gear apps (respectively) are used for personalisation (Chauhan et al., 2016). This personalisation is used to allow people to use their wearable devices as a fashion statement, similar to clothing and accessories.

In essence, personal uses of wearable devices are any uses not related to the profession or health of the user. Wearable devices often allow notifications from other devices (usually smartphones) to be viewed in a less obtrusive manner. Assistive technology is a growing area of use (e.g. sign language interpretation), as is augmented reality (e.g. navigation, education games). Emotionally sensitive computing is another area of personal fields of use. The ability to personalise wearable devices is also used to improve the fashion aspect of wearable devices.

2.3.2. Business

Many wearable devices are multi-purpose and have business fields of use. Mobile technology has been used to a positive effect in sales and has led to the rise of “nomadic computing”. Wearable devices may assist in these areas. In addition, some wearable devices are designed purely for business use. Specialised wearable devices exist to assist professional networking at events and to assist presenters at conferences.

Whilst the study of wearable devices in a corporate environment is lacking, studies have been done on mobile devices. In one study, sales teams increased sales with mobile technology although it was not always noticed by the team members (Scornavacca and Sutherland, 2008). The study’s results may also apply to wearable devices. This implies that benefits from use of wearable devices may not always be apparent to their users. One study aims to develop decision frameworks for executives to decide if/how to use wearable devices in their organisations (Robson et al., 2016).

Wearable devices and mobile devices also allow “nomadic computing”. While this can be beneficial, it can also cause business and personal life to merge, usually with the effect of work being done at the user’s home (Wiberg and Ljungberg, 1999). Wearable devices can compound this problem unless they are able to distinguish between the environments the user moves between.

Wearable devices are also useful in professional events, to assist networking between users. One of the more common ways of greeting another person in Western culture is shaking hands. To
allow people to share information about each other (akin to exchanging business cards), a paper proposed a band worn on the wrist that exchanges contact information with a similar band worn by another person when the wearers shake hands. When this system was trialled, the feedback was mostly positive, but it was suggested that the band should have an on/off switch for privacy reasons (Kanis et al., 2005). This system could also be implemented in smart watches.

Whilst the aforementioned system is useful for exchanging contact details, it serves only one purpose. A multi-purpose system for social environments was developed in the form of a badge. The badge is to be worn around the neck at devices such as conferences, in the same way that ID cards are worn at such events. The badges may communicate in the same manner as the aforementioned wristbands. The badges, however, have a LED screen and may display messages and vibrate to alert the user. In addition, the system helped presenters at events by showing them how far they were through their allotted time graphically. The badges also support input from sensors, a 3-way switch and 2 buttons (Paradiso et al., 2010).

At conferences a number of presentations are given. When this occurs, an accomplished presenter can gauge the interest level of the group and act accordingly. As this is an acquired skill, a system was developed to determine this using GSR (Galvanic Skin Resistance) and the amount of head nodding. In the study, an accurate model for a “group interest index” was produced (Madan et al., 2004). Head mounted displays have been tested to allow the attendees of a presentation to view extra information individualised to them, with a positive impact (Rijnsburger and Kratz, 2016).

Another possible use of head mounted displays is to use augmented reality (when adopted by a consumer) to improve communication with consumers via labelling and advertising (Vladić et al.). This, however, would require large scale adoption of augmented reality by consumers, unless it was deployed in the context of a trade expo or the like.

To sum up, wearable devices have a variety of uses in “white-collar” professions. They are known to assist in sales (when worn by salesperson or customer) and can assist in “nomadic computing” for any profession which requires travel. They also can be used to enhance networking at professional events (e.g. automatic contact detail sharing) and also can augment presentations for both the presenter (by detecting audience engagement) and for audience members (by providing extra information tailored to them).
2.3.3. **Industry**

A number of specific wearable devices have been developed for use in industry, therefore this is a major field of use for wearable technology.

Head-mounted displays appear to be the most common. The most studied use of wearable devices in industry is warehouse picking (i.e. gathering different parts of an order from within a warehouse). This technology also has many other applications. Wearable devices are also used in risk management (including fatigue detection), although such wearable devices do not usually make use of head-mounted displays. It has also been suggested that wearable devices can be useful in emergency situations for triage.

Warehouse picking is an area where a number of studies have been done with wearable devices. One such system implements a RFID reader into a glove and implants a small display onto the back of the glove. This allows warehouse pickers to read RFID tags of items that they touch (Muguira et al., 2009). A different approach involved using a HMD, which was tested against a paper list system, a paper map system and an audio based system (speech recognition) (Weaver et al., 2010). HMDs were shown to be faster than other systems in multiple studies (Weaver et al., 2010, Iben et al., 2009). It is worthy of note that a long-term study showed that expert workers’ productivity decreased when using HMDs, but untrained workers learned faster with a HMD (Funk et al., 2017). Augmented reality shows promise in this area, and has been trialled in a practical long-distance learning environment with some success (McFarlane et al., Vijay et al., 2016). A similar system was trialled at a university, giving instructions to students via a head mounted system (with relative success) (Ismail et al., 2017).

Augmented reality has also been studied in other industrial situations (Büttner et al., 2017). One such study involves using smart glasses to assist maritime pilots, allowing them to view navigational information without requiring them to look away from their immediate environment (Ostendorp et al., 2015). Similar studies of augmented reality in industry (in practise and in training) have been conducted (Aromaa et al., 2016, Hobert and Schumann, 2016, Mattmuller, 2016, Tamminen and Holmgren, 2016). One interesting study into wearable expert systems notes their ability to learn due to the data being gathered while in use (Sartori and Melen, 2017). One of the first studies of wearable technology in maintenance is the WearIT@Work study, focusing on automobile maintenance (Maurtua, 2009).
Risk management is another work-related area where wearable devices can be very useful. A study suggested that a “smart helmet” could inform the user when it is not properly positioned, and HMDs could warn the wearer if a load being lifted has a badly positioned hook. A basic system known as SmartHat has been tested, but has not yet been widely implemented (Teizer, 2015). Safety helmets have also been developed that allow the wearer to get assistance from an expert when performing a task via a microphone and camera (Skelton, 2016). It was also suggested that emergency workers biofeedback could be monitored (using a body are network) and their colleagues informed if they are in danger (e.g. if a firefighter’s oxygen levels get dangerously low) (Fugini et al., 2009). One study used wearable devices to determine the stresses firefighters experience when fighting wildfires (Parker et al., 2017). A number of safety based uses for wearable devices have been proposed (Le et al., Kim et al., 2016c, Persson and Kuzet, Greinke et al., 2016, Singh et al., 2017b).

Risk levels are also affected by fatigue, which may be detected by wearable devices. A model has been developed to allow for fatigue detection via wearable sensors (Sedighi Maman et al., Persson and Kuzet). Similar sensors may be used to detect stress levels, and a study has been done on assembly line workers to modify a worker’s tasks depending on the stress levels of the worker (ElKomy et al., 2017).

Whilst not strictly industrial, a heads-up wearable has been tested for the purpose of environmental research. Various sensors in the wearable measure environmental factors (Delabrida et al., 2016). A similar system has been prototyped for triage and hazardous material identification in emergency situations (Berndt et al., 2016), and it has been suggested that wearable devices could be useful in other disaster scenarios (Cheng and Mitomo, 2017). In conclusion, the main industry use of wearable devices is in warehouse picking, using augmented reality systems, which is known to increase efficiency. Studies in other areas have been done (e.g. maritime pilots) but are not in mainstream use. Risk management is also an emerging area, as is management of emergency situations (in both triage and front-line personnel).

### 2.3.4. Wellbeing

A large number of people own activity trackers and other wearables related to their health in a non-clinical context. This field of use may be known as Wellbeing.
Wellbeing uses of wearable devices tend to fall into three categories. The largest category may be considered to be activity tracking, where wearable devices are used to measure steps or other information about the wearer to quantify and encourage exercise. Secondly, some wearable devices are designed to detect medical issues before they require intervention in a clinical situation. Finally, wearable devices are also used to measure performance at a specific sport (e.g. skateboarding), with the aim of improving performance.

Fitness trackers are quite commonplace as a consumer wearable and appear to be used extensively. It also suggested that habit formation, social motivation and goal achievement may encourage wearable use in the long term. Fitbit (Fitbit Inc., 2015) devices use a series of “badges”, linked to the amount and type of exercise done in a day or over time. Gamification has been shown to increase the usage of wellness wearable devices (Kim, 2015). The user receives a “badge” when they make a personal record. Angulo (2016) discovered that the achievements (in conjunction with the social competitiveness) encouraged users to become more active. The study did note, however, that the device itself was a facilitator (in allowing them to measure their steps) rather than a motivator. However, alerts to remind users to do exercise have also been shown to be useful in increasing activity (Zook, 2016). Interestingly, activity tracking wearable devices have also been used successfully to estimate the happiness of the wearer (Yano et al., 2015).

Some corporations have deployed fitness trackers to their staff, to encourage exercise. When this occurs, along with offering incentives (e.g. rewards for the best team of employees step-wise), it can lead to employees leading a healthier lifestyle in a number of areas (Giddens et al., 2017). General activity tracking wearable devices can also be used to assist people with medical issues. Fitness trackers have been shown to increase exercise and general wellbeing in people who are obese and mentally ill (Naslund et al., 2016). This has also been noted in adults over 55 (without other issues), when combined with telephone counselling (Lyons et al., 2017). A similar system was used for alcoholics, taking biofeedback measures and warning them when they were at risk of relapsing (Enewoldsen, 2016). Google Glass was tested as an assistive mechanism for people with Parkinson’s disease, but it was discontinued due to technical and ethical issues (Vines et al., 2016).

It has been suggested that smart clothing could gather large amounts of data which can be then used in a clinical or non-clinical context for wellbeing (Chen et al., 2016, Trindade et al., 2016,
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Yin, 2017). One such use has been proposed where the wearable alerts the user when there is a problem, and alerts emergency services if necessary (Athavale and Krishnan, 2017). Systems have been developed using an adaptive fabric that may improve the user’s posture, some of which adapt to hot/cold weather to help the user maintain an optimal temperature, improving the user’s comfort and lowering the chance of illness (Durbhaka, 2016, Lin et al., 2016, Wang et al., 2016).

Highly athletic users of wearable devices may use specialised wearable devices to gather data to aid their performance. Accelerometer-based wearable devices have been used to model and classify skateboard tricks with success (Groh et al., 2017), and similar sensors have been used in other sports to aid athletes’ performance, including dancing (Howe et al., 2017, James, Santos et al., 2017). Kos and Kramberger (2017) also prototyped such a wearable. The capture of biometric information raises privacy concerns, and one study investigates these concerns in a case study of professional sport (Karkazis and Fishman, 2017).

Augmented reality (AR) has also been used to assist in training/coaching in some sports. An AR system was prototyped to coach users in tennis. It was discovered that a visual-only system (i.e. no sound) was the optimal way to provide information to the user (Kim et al., 2017). It should be noted that this study focused on fast-paced sports. The optimal method of presentation may differ in slower activities.

To summarise, the majority of wellbeing fields of use involve activity trackers, which assist in encouraging and quantifying exercise. These devices along with smart clothing also may assist in monitoring medical conditions. Some athletes use wearable devices to monitor and improve their performance, both in activity trackers and augmented reality systems.

2.3.5. Medical

Medical uses for wearable devices encompasses the use of wearable devices in a clinical setting, as opposed to wellbeing wearable devices. There are three major medical fields of use for wearable devices. Firstly, some wearable devices are used for medical monitoring of patients. Secondly, wearable devices can be useful in theatre when surgeries are being performed. Finally, wearable devices are used for treatment, generally with respect to the recovery of patients.

With respect to the first use case, multi-modal monitoring systems (including wearable devices) may allow people at risk of medical emergencies to live independently, with biofeedback sensors
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(amongst others) that can send an alert when a possible issue is detected. (Kumari et al., 2017, Lin et al., 2016, Ali and Li, 2016) explains how such a system could work. Another interesting system maps users actions to pain levels (determined via biofeedback) and assists with pre-empting painful actions and allows the user to avoid them or to know the best method to cope with said pain (Singh et al., 2017a). A similar system exists for mobility assessments of wearers (Sprint et al., 2016).

Many similar multi-modal monitoring systems have been proposed which may assist in diagnosis of conditions/illnesses/mental episodes as well as medical research (Ali and Alyasseri, 2017, Chauhan and Bojewar, Gaskin et al., 2017, Emaminejad et al., 2017, Li et al., 2017a, Munos et al., 2016, Polanco et al., 2017, Sutar et al., 2016, Webster et al., 2017). Mining these large amounts of data may allow insights into medicine that were not available before (Zhang et al., 2017).

These wearable devices have many varied uses. Such a system could also be used to monitor users with cognitive disorders such as Alzheimer’s (Shenvi et al.). It has also been proposed that augmented reality systems could allow caregivers to assist senior citizens remotely with navigation and the like (Deng, 2016, Kashimoto et al., 2016). One wearable looks for signs of PTSD episodes, and reacts with Internet of Things devices accordingly (McWhorter et al., 2017). An interesting system measures brain activity from a headband, although no use was suggested for EEG data in the paper (Wiechert et al., 2016). Some systems make use of “smart shoes” or insoles to collect medical data (Hwang et al., 2016b, Najafi et al.).

Such multi-modal monitoring systems can also give the user’s medical practitioners more information than the user, and real-time data transfer allows the user to be clinically monitored without being physically present (Jeon et al., 2017).

The second major use case occurs when the data indicates that the patient will require surgery. A systematic review of wearable technology in operating theatres concluded that wearable devices show promise, but there are few clinical trials. It also noted that technological limitations must be addressed, specialised applications must be developed and privacy risks must be managed before wearable devices become commonplace in operating theatre environments (Kolodzey et al., 2016). Once such trial involves the use of augmented reality in spinal surgery (Golab et al., 2016).
Augmented reality has been used to assist teaching of neurosurgery, but technological limitations have decreased its usefulness (Sahyouni et al., 2017, Lemos et al., 2017). Smart glasses have also been proposed for use in other areas (Chandran, 2017, Mentler et al., 2016, Templeman et al., 2016). Nurses may also benefit from the use of wearable technology with respect to their duties (Wilson, 2016, Bang et al., 2015).

It is worthy of note that a test of head-mounted displays in simulated emergency situations showed no improvement at all in patient care (Kutzin et al.).

A HMD system is used for immersive gaming to determine upper limb dysfunction (Cidota et al., 2016), and a system has been designed to assist recovery in some cases (Crema et al., 2017). Similar recovery systems (without HMDs) exists for other forms of rehabilitation (Lambelet et al., 2017, Ploderer et al., Wang et al., 2017). Worn accelerometers have been used to determine recovery in children after surgery, with some success (Ghomrawi et al., 2017). Rehabilitation systems are sometimes cumbersome, and this must be changed for wearable devices to be useful in rehabilitation (Pektekin et al., 2017).

Interestingly (whilst not directly related to a use case) users highly value informed consent with respect to their health data but they do not seem to respond similarly to privacy issues with their health data (Segura Anaya et al., 2017, Bellekens et al., 2016).

In summary, many medical monitoring systems exist that allow users to live independently while being medically monitored or allows them to be mobile in an assisted living/hospital situation. Wearable devices may also assist medical staff both in and out of theatre and can assist patient in recovery from injuries. It should be noted that users strongly value informed consent with respect to the collection of data from these wearable devices.

2.4. Usability

To allow wearable devices to be useful, usability must be considered. The current literature about research into wearable usability is examined in this section. This section is divided into four parts. Section 2.4.1 covers all the research specifically into the usability of wearable technology. Section 2.4.2 enumerates the research into usability of mobile technologies which may also be applied to wearable technologies. As design processes for wearable devices (and mobile technologies) can differ from traditional methods, section 2.4.3 covers research in this
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area. A number of companies have developed usability guidelines specific to their wearable device(s), although they may be generalisable. These guidelines are presented in section 2.4.4.

2.4.1. Wearable-specific research

This section discusses the usability studies specifically related to wearable devices. This section starts by discussing generalisable studies into wrist-mounted wearable devices and then mentions studies into specific aspects (especially screen size/shape). Finally, the literature about usability testing of wearable devices and the effect of demographics on the results is discussed.

Although wearable usability studies are rare, some studies (Lowens et al., 2015, Isacson, 2015, Asimakopoulou et al., 2017) do investigate the usability of wearable devices, but only wrist-worn wearable devices. Marin et al. (2017) describes a framework for physical design with respect to usability, but only for motion capture (e.g. activity tracking) wearable devices. One thesis provides five user experience guidelines for all wrist-mounted wearable devices (Löfblom, 2017).

Other studies that exist look at specific aspects of wearable usability. One study looks at how web sites can be optimised for small screens (both mobile and wearable), and it generates some principles (Kärkkäinen and Laarni, 2002). Germperle et al (1998) suggests guidelines for physical design of wearable devices, but does not look at the usability of the wearable device.

With respect to physical design, screen shape and size have been shown to affect usability. Larger screens increase the hedonic and pragmatic usability of a smartwatch. If the screen is round, the effect is generated by hedonic aspects, whereas square screens also include pragmatic aspects. It has also been shown that text and images, as compared to text only) impact usability (Kim, 2017).

In usability testing, the demographics of the users tested must be taken into account, as different demographics may experience different issues. The above statement has been shown to hold with respect to wearable testing. A study of older people using Google Glass (Google Inc., 2015b) identified some usability issues and makes a number of recommendations that may improve the software experience (Haesner et al., 2018). Younger people also have been studied using Google Glass (Google Inc., 2015b) and they found comfort (e.g. device overheating, wearing with reading glasses) and usage complexity to be the main factors inhibiting adoption intention (Dafoulas et al., 2016).

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Age has also been shown to affect the risk of cognitive overload (i.e. showing too much data at once). A system that learns from the user with respect to how much data to display at one time has been prototyped and proven to be effective (Tsai and Huang, 2017).

2.4.2. Mobile research

This section discusses literature into mobile device usability that may be applied to usability of wearable devices. In this section, some studies into mobile usability are discussed, followed by a discussion on how context-awareness research and “benevolent deception” may be useful in wearable usability. Finally, mobile usability testing research is discussed and how it’s insights may be useful in designing wearable usability testing.

Wearable devices present unique usability challenges, but some studies about mobile usability provide insights that may be applied to wearable usability. Context awareness is a specifically useful property that may be applied to wearable user experience design.

There are a large number of studies that look at usability principles for mobile devices (Tarasewich et al., 2008, Zhang and Adipat, 2005, Ji et al., 2006). A number of these principles are useful for wearable devices. Various models have been suggested for development of usable apps (Zhang and Adipat, 2005, Harrison et al., 2013).

It has been suggested that context-awareness is of great importance in mobile applications (Häkkilä and Mäntyjärvi, 2006), which is likely to be the same for wearable devices. A review of a number of studies suggests that interfaces be developed for one context of use, but should be flexible to account for other fields of use, take into account human (e.g. cognitive and physical) factors, and understand that the interface is not the only part of the interaction (Coursaris and Kim, 2011). One interesting method for detecting context uses motion-based energy harvesting systems (Sara et al., 2018).

To allow users to accept technology, sometimes “benevolent deception” can assist the user’s transition. Benevolent deception, such as a camera app making a shutter noise when a picture is taken, helps bridge the gap between the user’s mental model and the system model. This must be used with caution, as users don’t always like being fooled (Adar et al., 2013).

When testing mobile usability (and through extension, wearable usability), it is important that context is observed. It has been shown that contexts (e.g. work, home, moving, standing) in
usability testing must be separated as the context can greatly affect the test results (Brown and Palvia, 2014, March and Storey, 2008, Duh et al., 2006, Kjeldskov and Stage, 2004). It may be suggested that mobile and wearable devices should adapt depending on the context they are being used in.

### 2.4.3. Design process research

The process of wearable design faces issues similar to mobile design, as the environment in which the technology is used is not static. It has been suggested that user-centred design may provide a framework for users to gather views and beta-test wearable devices before full deployment. In addition, a framework for such a system is discussed. In conclusion, a study is cited that shows how usability affects the concerns (privacy and trust) when using a wearable.

User-centred design may be used in the development of wearable devices. Some research provides a framework to gather users’ views on wearable devices before the wearable devices are deployed, and a way to analyse their views (Sohail et al., 2016). Once prototyped, iterative usability testing has been shown to be effective when the system is deployed in a real environment (similar to beta testing) (Skattor, 2008). This can also be augmented by prototyping before the system is deployed.

A framework does exist for software prototyping that aims to avoid paper prototyping issues (de Sá et al., 2010). One paper suggests that data analysis on-the-fly (also known as Instant Data Analysis) can identify approximately 85% of usability issues in a very short time frame (Kjeldskov et al., 2004). This was not tested with wearable devices, but it may apply, especially with the amount of data gathered by wearable devices.

Usability has also been shown to affect the users perception of data practices, affecting the concern of users about their privacy and trust in the wearable (Lamb et al., 2016).

It has been suggested that usability guidelines are not always well-formed and are therefore not followed. A series of meta-guidelines have been proposed to allow for good formation of guidelines (Cronholm, 2009). It has also been suggested that guidelines be tied to system components for usability purposes (e.g. GUI, hardware, OS) (Kim et al., 2008).
2.4.4. Corporate Usability Guidelines

As wearable devices are a relatively new field, there are no established usability guidelines. In an effort to standardise app development, a number of companies creating wearable devices have developed guidelines for their designers. This section covers the guidelines that have been developed by companies for their wearable devices.

2.4.4.1. Samsung Gear

Samsung has published a set of interface guidelines for its flagship wearable, the Samsung Gear (multiple versions) (Samsung, 2014a, Samsung, 2014b). Whilst the vast majority of the guidelines are specific, there are four design principles which are relevant to all wearable devices.

The first principle states that information should be “glanceable” (able to be understood at a glance). The information should be “bite-sized” to allow the user to quickly glance at their wearable and understand the information.

The second principle states that all interactions (especially on the small screen) should be natural, simple and minimise user’s concentration. This concept is described as “actionability” by Samsung.

The third principle dictates that the wearable should be customisable to allow the user to express themselves (using the wearable as a fashion item). The guideline says that interaction should be “delightful”, by the use of “vivid graphics, rich text and flexible content layouts”. It may be construed that this guideline increases social acceptability of the wearable.

The final principle says that the wearable should be a companion to another device (Samsung mobile phone in this case), rather than a standalone device, and should allow the user to switch between both devices seamlessly. Whilst seamless switching is a good principle, it should be noted that a number of wearable devices are designed to operate independently.

<table>
<thead>
<tr>
<th>Samsung Gear Principles</th>
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<tbody>
<tr>
<td>Glanceable</td>
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<tr>
<td>Simple actions</td>
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2.4.4.2. Microsoft Band

Microsoft has released design guidelines for a “smart watch” called the Microsoft Band. It has six design principles for the user interaction (Microsoft Inc., 2015a).

The first principle is “Direct, yet discreet [sic]”. It may be assumed that the word “discreet” is the intended word, rather than “discrete”. The principle states that notifications should be timely, but not disruptive and should be easily dismissed. This is consistent with the “peripheral interaction” described in the definition of wearable technology.

The second principal flows from the first and is titled “hyper-glanceable”. It states that information should be visible easily and quickly.

Thirdly, the device is “not a mini phone”. Microsoft states that the Microsoft Band should display enough information to let the user know if they need to get their phone out.

Fourthly, the device should be “forgiving”, allowing compensation for error and a “non-destructive” interface.

Tying into the second principle, the fifth principle is “in and out in eight”. Any piece of information should be able to be digested and acted upon within 8 seconds.

The final principal is called “about me”, and states that the device should learn about the user and anticipate the user’s needs. This is a form of context-awareness.

<table>
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<tr>
<th>Microsoft Band Guidelines</th>
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<tbody>
<tr>
<td>Peripheral interaction</td>
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<tr>
<td>Glanceable</td>
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<tr>
<td>Not a phone replacement</td>
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<tr>
<td>Forgiving</td>
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</table>
2.4.4.3. Android Wear

Google, as the owners of the Android platform, have released six design principles for Android Wear devices (Google Inc., 2015a).

“Focus on not stopping the user and all else will follow” is the first principle suggested by Google. Google recommend that designers ensure that their app interaction is no longer than 5 seconds, and that their app can be used during a conversation without affecting the user’s train of thought or eye contact with the other person.

“Design for big gestures” is the second principle. The user has limited screen space, so Google points out that a high level of precision is not feasible. It is suggested that, if the user must slow down while walking or pause a conversation to be precise enough, the level of precision required is too high.

The third principle “think about stream cards first” is less self-explanatory. Android wear devices use “cards” to display information. This principle suggests that an Android Wear app should try to anticipate when the user will need a card. In essence, the design principle encourages context-awareness.

“Do one thing, really fast” is the fourth principle and states that each “card” should contain one bit of information and should be able to be dealt with quickly and simply.

The fifth principle ties into the fourth principle, and it is called “design for the corner of the eye”. Google suggests designers focus on their knuckles and work out if they can distinguish the basics of their card from peripheral vision. This is also called “glanceability”.

The final principal is “don’t be a constant shoulder-tapper”. Google compare the vibration of a watch to a tap on the shoulder to gain attention. It is suggested that the app should only cause the watch to vibrate when the interruption justifies suspending a conversation the user may be having.
Table 5 - Android Wear Guidelines

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<th>Android Wear Guidelines</th>
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<tbody>
<tr>
<td>Fast interaction</td>
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<td>Low precision interaction</td>
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<td>Context-aware information</td>
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<tr>
<td>Single event interaction</td>
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<tr>
<td>Glanceability</td>
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<tr>
<td>Limit intrusive alerts</td>
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2.4.4.4. Apple Watch

Although Apple has released Human Interface Guidelines for the Apple Watch, most of them are very specific to the Apple Watch (Apple Inc., 2015b). There are only two principles which are general.

One of these principles is “lightweight interactions”. The guideline states that interactions should be fast and efficient. The interaction should display minimal information and should be dismissed easily.

The other principle is called “personal communication”. This principle states that the device is always present on the user and is therefore “closely connected”. It asks the designer to be aware of the “close connection” but does not elaborate. It may be assumed that Apple is suggesting discretion and context-awareness should be considered.

2.4.4.5. Pebble

The Pebble smart watch has seven design guidelines for application developers (Pebble, 2015). These guidelines are built from 5 basic principles.

The first guideline is that layouts should be simple, only displaying the information immediately required. This allows the user to comprehend and respond quickly to the information on the screen. This guideline is aided by a number of the other guidelines.
The second guideline states that the most commonly used and main functions of an app should be easy to find (while not obscuring other options). This guideline is unique to the Pebble, as Pebble apps are not necessarily tied to smartphone apps.

The third and fourth guidelines aid the first guideline. The third guideline states that font size should be used to show the importance of a message. The fourth says that colours should be used to avoid text needing to be read where possible (e.g. green to show that a task was completed).

Conversely, the fifth guideline suggests that the designer avoids misleading colours, such as red when there is no error.

The sixth guideline recommends animations be used to draw the attention of the user when something is updated or changed.

Finally, the seventh guideline suggests that the interface gives direct feedback to the user, to ensure that the user knows that their actions are having an effect.

<table>
<thead>
<tr>
<th>Pebble Guidelines</th>
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<tbody>
<tr>
<td>Simplicity</td>
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<tr>
<td>Ease of finding actions</td>
</tr>
<tr>
<td>Large font size</td>
</tr>
<tr>
<td>Colour-based information</td>
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<tr>
<td>Avoid misleading designs</td>
</tr>
<tr>
<td>Animate change/update</td>
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<tr>
<td>Give direct feedback</td>
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Table 6 - Pebble Guidelines

2.4.4.6. **Summary**

The design guidelines for the various types of wearable devices overlap significantly, and the common guidelines are shown below in Table 7.
There are a number of guidelines that are useful in wearable usability that may be useful, and provide concrete guidelines, such as having a large font size and using colours to convey information (Pebble). The guidelines all agree on the fact that information should be conveyed in a glance, interactions should be fast, simple and limited to one per screen, and the system should understand its context of use.

It is worthy of note that these guidelines intersect with the definition of wearable technology formed in section 2.1. They differ in the fact that the definition defines what a wearable is, whereas these guidelines are focusing on making wearable devices usable. This would make a comparison between the two unhelpful, similar to comparing apples and oranges.

### 2.5. Motivations

This section encompasses the research into the motivations behind the use of wearable technologies.

Whilst the motivations of wearable usage are to be researched in this project, this section discusses the current state of research into this area.

This section is divided into two sub-sections, as the motivations to start using wearable technologies differ from the motivations that promote continued use of a wearable. Section 2.5.1 focuses on the uptake of wearable technologies. As motivations can significantly differ between the type of wearable, this section is separated accordingly, with section 2.5.1.4 covering motivations that tend to affect the uptake of all wearable devices. Section 2.5.2 investigates the motivations behind continuing to use a wearable after the wearable has been purchased and the
“new and shiny” aspect no longer applies. The research suggests that the motivations for continued use are different to the motivations to adopt a wearable (Canhoto and Arp, 2017).

2.5.1. Uptake

In this section, the motivations behind the user starting to use a wearable are discussed. As motivations tend to differ between different types of wearable devices, Activity Trackers (section 2.5.1.1), Smart Watches (section 2.5.1.2) and Head Mounted Displays (section 2.5.1.3) have individual subsections that discuss their specific motivations. General Uptake (section 2.5.1.4) discusses the motivations that are common to all wearable devices.

2.5.1.1. Activity Trackers

Activity trackers are, arguably, the most common wearable from a consumer perspective. There are many studies into the adoption of activity trackers (Canhoto and Arp, 2017). There are two main areas with respect to adoption studies of activity trackers. The first, and largest area, is the determination of the factors that affect adoption. The second area focuses on specific groups that may benefit from the use of an activity tracker.

With respect to the first area, One study of 206 users concluded that perceived factors (usefulness, enjoyment, and wellbeing benefits, innovation) along with social impact and trust in the device were the main factors that affected uptake of activity-tracking wearable devices (von Entress-Fürsteneck et al.). Another study supports these conclusions (Chang et al., 2016).

Some other studies suggest that gamification can also be a significant factor in the acceptance of an activity tracker (Nelson et al., 2016, Spil et al., 2017).

It is worthy of note that users are generally loyal to a device (or device manufacturer), regardless of whether they decrease their use of said device or stop altogether (Canhoto and Arp, 2017).

Regarding specific groups of people that may benefit from activity trackers, it has been shown that teenagers generally achieve benefits with fitness trackers initially, but these benefits do not continue in the medium to long term (Goodyear et al., 2017). However, in a study of third year students, they did do more activity when an activity tracking wearable was linked to a game, and the teaching aspect of the game was more effective when linked to physical activity (Lindberg et al., 2016), which supports the gamification studies mentioned previously. The activity-based game Pokémon Go also has been shown to increase physical activity (Althoff et al., 2016).
Other studies have been conducted on groups of people with medical issues, where extra movement may assist. One study was conducted on people over 50 with chronic illness. These people were perceived to be sedentary, and it was proposed that activity trackers may increase their level of movement, should they accept them. It was shown that, after trialling multiple activity trackers, 73% decided to purchase an activity tracker and use it to quantify their exercise (Mercer et al., 2016).

Activity trackers have also been used by breast cancer survivors to increase physical activity (as it assists with survival rates). The study showed that acceptance was helped by peer and medical support, as well as clear instructions on how to use the device features (Nguyen et al., 2017).

2.5.1.2. Smart Watches

Smart watches are available to consumers currently, and a number of studies have been done to suggest what aspects affect the uptake of smart watches (mostly emotive and perceived advantage). Also, studies into why users may not want a smartwatch have been conducted (generally usefulness and battery life).

The emotional impact of a smartwatch appears to be the most compelling reason to adopt a smartwatch, with the perceived advantage also playing a significant role. A study of 273 users in Korea discovered that emotional design and content quality were the main factors in adoption of smartwatches (Cho and Park, 2016). A similar study in Taiwan claimed that only attitude (mostly aesthetics) affected uptake, but social impact and performance/value had no effect (Hsiao and Chen, 2017). A large study of 341 potential smartwatch adopters concluded that perceived relative advantage was the main factor affecting adoption (Hsiao, 2017).

There have also been studies into why users may not adopt smartwatches. (Ha et al.) discovered three issues that act as barriers to adoption of smartwatches. Firstly, users perceive the smartwatch as a set of sensors, rather than a watch with extra features. Secondly, battery life is a concern, but is seen as a trade-off. Finally, users tend to think about a brand name or model name of a smartwatch, rather than the features that they want.

2.5.1.3. Head Mounted Displays

Head mounted displays (HMDs) and augmented reality systems are relatively new (especially in a consumer space) and, therefore, there are not a large number of studies. However, the studies that do exist are specific to HMD and therefore warrant their own section. The most common
issue studied appears to be privacy. Social acceptability has also been studied, as has the effect of gratification and substitutability (replacing a physical object with a virtual object).

The most common issue affecting uptake of augmented reality (AR) and HMD systems is privacy. A number of systems can record video, causing privacy issues for non-users of the systems (Ge, 2016). Smart glasses especially pose a number of ethical issues with their use, privacy being a significant concern (Hofmann et al., 2016). One study, however, concludes that fashion and privacy concerns do not affect the uptake of augmented reality systems (Rauschnabel and Ro, 2015), although it should be noted that privacy concerns may be stronger in the people surrounding the user of the wearable (rather than the user).

Social acceptability of HMDs can be an issue, but should a user have a visible disability, their use of head-mounted displays is usually deemed socially acceptable in situations where it would not normally be (Profita et al., 2016).

One study on the uptake of augmented reality (in the form of smart glasses) developed a model to match human needs to gratification provided by augmented reality systems (Rauschnabel and Ro, 2015). It has also been suggested that perceived substitutability (the ability for augmented reality systems to create an appearance of a physical object when one does not exist) directly affects perceived usefulness and perceived enjoyment of AR systems (Ernst et al., 2016).

2.5.1.4. General Uptake

There are a number of studies into uptake of wearable devices that are generalizable amongst many wearable devices. The majority of studies investigate which factors affect uptake and seek to enumerate them. Other studies go into depth into certain factors. In this section, studies into the factors of social acceptability, privacy, fashion and usability are mentioned. Next, studies about the differences between different groups of people (with respect to uptake) are covered. Finally, specific studies into factors that affect the uptake of clinical wearable devices are discussed, along with usability aspects that may affect uptake.

Technology adoption is a social factor that must be considered. A study has investigated adoption of mobile technology, and wearable technology could be assumed to be affected by the same factors (Kim and Ammeter, 2014).
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A common model used in adoption studies is the Technology Acceptance Model, which has been superseded by the UTAUT (Unified Theory and Acceptance and Use Of Technology) and UTAUT2 models (Venkatesh et al., 2012, Venkatesh et al., 2003).

A study applied the Technology Acceptance Model to wearable devices and discovered that visibility and usefulness affect uptake (Rauschnabel et al., 2016). This has been contradicted by a different study stating that ease of use is not an important factor, whereas attitude and enjoyment are (Wu et al., 2016). Another study extended the Technology Acceptance Model with respect to smart clothing (focusing on solar powered clothing) (Hwang et al., 2016a).

In China, value, quality, and trust appear to be the main factors in the adoption of health-related wearable devices (Gu, 2016, Gao et al., 2016). Jusob (2016) developed a trust model for wearable devices, which allows for increased uptake. In the US, acceptance of a personal safety device (issued to all students) was studied by extending the UTAUT model to include trust (Potnis et al., 2017).

A separate study in 2016 had participants test a smart watch and an augmented reality system (separately), and found the main factors affecting adoption to be: fitness apps, notifications, GPS (and GPS accuracy), water resistance and handsfree operation (Adapa, 2016). Interestingly, a round screen appears to increase uptake of wearable devices, but it negatively impacts the controllability of the device (Kim, 2016). Ledger and McCaffrey (2014) suggest a number of criteria that can encourage adoption, but note that the criteria do not ensure long-term use. The criteria are adoptability (ease of selection of device), aesthetics, setup experience, comfort, quality, user experience, integratability (with other systems), lifestyle compatibility and overall utility.

Whilst the above studies provide a wide variety of criteria affecting uptake, social acceptability has been studied separately as an aspect of wearable uptake.

A pair of studies in 2014 and 2016 (conducted in Turkey), discovered that social value dimensions of wearable devices were more prevalent in determining intention to purchase a wearable (Dastan, 2016). A 50 point scale known as the WEAR (WEarable Acceptability Range) scale has been proposed to measure social impact of a wearable (Kelly and Gilbert, 2016). An online (survey-based) study suggested that perceived attributes strongly affect adoption of smartwatches, primarily relative advantage (Hsiao, 2017). Smart glasses have also been the subject of uptake studies (Basoglu et al.).
One study concludes that perceived usefulness, social influence and perceived privacy issues impact the uptake of wearable devices (Choi et al., 2017).

Privacy also appears to be a significant concern of users. This concern extends to “life-logging” devices that automatically capture pictures (Ali, 2016). Interestingly, one study shows the 16-25 year old demographic to be the most concerned about their privacy (López et al., 2016). This was also borne out in a study with locating devices for passengers on ships, although privacy concerns were also affected by concerns for safety (Kwee-Meier et al., 2016). Another study focusing on a young demographic finds that privacy is not a high concern for university students with respect to wearable devices (but it is with respect to smartphones) (Udoh and Alkharashi, 2016). Privacy may be a concern, however, when personal information is shared with a company. A study shows this to be the case when fitness trackers were issued by an insurance company (Paluch and Tuzovic, 2017). A framework for making health systems privacy-aware has been proposed (Thinakaran et al.).

Naturally, different types of people are affected by different aspects when deciding whether to use a wearable, and what kind of wearable to use. Behavioural traits, cultures and ages are known to have an impact.

Behavioural traits have also been shown to affect uptake of wearable devices. A study in China discovered that fun-seeking people will adopt wearable devices when their perceived ease of use is low, but reward-oriented people will adopt wearable when their perceived usefulness is high (Rajanen and Weng, 2017). It has also been shown that the perceived usefulness is a stronger factor than enjoyment with respect to the continued use of a smartwatch (Hong et al., 2017). It has been noted that uptake factors can differ between cultures (Koo, 2017). Older adults tend to prefer comfort, familiarity in materials and device independence in wearable devices (Nevay and Lim). The also prefer larger screens (for readability), and prefer wrist-mounted wearable devices (Fang and Chang, 2016).

A study of clinical wearable devices has concluded that clinical wearable devices must be stylish and demonstrate their effectiveness to be acceptable to wearers (Ozanne et al.). Other studies reach the same conclusion (Chuah et al., 2016, Gribel et al.).

Clinical wearable devices are not the only wearable devices whose uptake is affected by fashion. One study in Korea determined that perceived self-expression and perceived enjoyment were drivers for adoption of smartwatches, and that these were affected by the fashion aspect of the
wearable (Choi and Kim, 2016). Another study about the adoption of smart glasses show that adoption is improved when the glasses are designed from a fashionable aspect (in addition to a technological aspect) (Rauschnabel et al.)

Usability is an important factor that can affect technology adoption. A study on the adoption of mobile technology shows that perceived complexity and perceived cost (including mental cost) can affect the adoption of technology (Kim and Ammeter, 2014). In addition, the perceived functional and emotional value affect adoption (Cakmak and Basoglu, 2012). The tasks to be performed may also affect the acceptance of the technology too (Fang et al., 2006). It stands to reason that these principles should also apply to wearable technology. A model has been developed to predict wearable technology acceptance (Kim and Ammeter, 2014).

2.5.2. Continued Use

The factors that affect the continued use of wearable technologies differ from the factors that cause the user to begin using a wearable, as one study makes note of (Canhoto and Arp, 2017). The same study also discovered than intrinsic goals motivate wearable use more than extrinsic ones. There are two major factors in that affect this. The first, and most significant factor, is the disillusionment of the wearable not meeting the expectations of the user. The secondary factor is the social impact of the technology.

Firstly, many users appear to have expectations of their wearable that are not met. One of the common expectations is that wearing an activity tracker will make the user heathier without effort on their part.

Lundell and Bates (2016) discovered that 27% of users used their Apple Watch less or not at all after 120 days. This was generally due to expectations not being met. When a similar study was performed with Fitbit fitness trackers, 75% stopped using the device in under 30 days, although the devices were provided in this study, not purchased by the user. The same study discovered that the main reasons for this were forgetting to wear the device, the device being impractical or unfashionable, issues with managing the data collected and issues with the accuracy of data collection such as a mismatch between steps taken and steps counted (Shih et al., 2015).

Clawson et al. (2015) did a larger study specifically on abandonment of fitness wearable devices. Out of 1600 second-hard wearable devices for sale, over 400 were being sold due to disillusionment when the wearable did not lead to the benefits that they expected. If users
achieve the results they expected, they are more likely to continue to use an activity tracker (Lunney et al., 2016). A study investigated this disillusionment and discovered some strategies to mitigate abandonment from this (Rapp and Cena, 2016). Kim et al. (2016a) also noted that people who use automated systems tend to record their activity for approximately four times longer than those who manually record their activity.

It is worthy to note that another study suggests that the major factor in abandonment is comfort and the form factor aspects of a fitness tracker, followed by the tracker not providing adequate information (e.g. not detecting cycling). Interestingly, fashion was among the most minor concerns of the wearers (Coorevits and Coenen, 2016).

Fashion and social impact are not the same thing, although fashion is a part of social impact. For a system to have a positive social impact, it must be aware of its impact. A context-aware system can determine an appropriate response for the context the user is in. The interaction must also be meaningful to the user. The meaning to the user can be more important than the simplicity/usability of the system physically does (Dourish, 2001). It has been shown that the perceived usefulness is a stronger factor than enjoyment with respect to the continued use of a smartwatch (Hong et al., 2017).

The social impact of smartwatches with respect to checking the watches has also been studied, and concluded that smartwatch users are concerned about the social cue of regularly checking their smartwatch, but the evidence about their acceptance of other smartwatch users doing the same is inconclusive (Fruehauf and Al-Khalifa, 2016).

Wearable devices are still relatively new, and it was proposed that sometimes it may cause the wearer to feel like an outsider, if the wearable is overt enough. To test this theory, some participants were asked to wear a shirt that displayed live games of noughts and crosses (Tic-Tac-Toe) being played. The participants did not feel uncomfortable and the level of attention was less than expected (Puikkonen et al., 2011). In a different study, a business suit was fitted with wearable technology and unobtrusive interfaces, to hide the technology rather than normalise it (Toney et al., 2003).

2.6. Work-Home Interference

This section investigates Work-Home Interference (WHI). In this section, the effects of smartphones on WHI and the impacts of WHI on health and productivity are discussed. In
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conclusion, the possibilities of WHI with respect to wearable devices are discussed in conjunction with BYOW (Bring Your Own Wearable) support by organisations.

Work-Home interference (WHI) is the intrusion of professional time onto personal time or vice versa (i.e. bringing work home). Mobile devices allow for this, and wearable devices may allow for an increase in WHI (as they are usually worn all the time). There are no studies in WHI for wearable devices, but it has been predicted that Bring Your Own Wearable policies may soon exist in workplaces. Bring Your Own Device policies may be a factor contributing to WHI. There are strategies to alleviate WHI, and WHI has been shown to have detrimental effects in many ways.

Mobile communication and the ubiquity of Internet access allow the distinction between home and work life to be blurred. The rise of BYOD (Bring Your Own Device) has led to personal devices being used for work purposes. The rise in device support for such use is assisting this phenomenon (Google Inc., 2017).

Derks et al. (2014) investigates the role of smartphones in recovery activities (e.g. psychological detachment from work, relaxation) as well as the role of mobile technology in WHI. It discovers that smartphone users tend to have more trouble completing recovery activities due to WHI. A different study (Derks and Bakker, 2014) shows that intensive smartphone use contributes to WHI, possibly due to the perception of availability at all times.

To alleviate the effects of WHI, some people use specific methods to disengage from work when at home using a number of different tactics to minimise or eliminate WHI (Kreiner et al., 2009). This appears to abate the effects of WHI for such people.

As WHI can be detrimental to the health, wellbeing and productivity of technology users, it must be taken into consideration (Geurts et al., 2003). Other studies show that WHI may not be detrimental in certain jobs (Taris et al., 2006) Whilst no studies into the effect of wearable devices on WHI, it may be assumed that the effects of wearable devices may be similar to the effect of smartphones on WHI. It is possible that wearable devices may have a greater effect than smartphones, because wearable devices are designed to be with the user at all times, whereas smartphones are “detachable”.

No studies exist in WHI with respect to wearable devices at this time. Studies do, however, exist with respect to mobile technology and WHI. It may be assumed that such effects will be amplified in wearable technology, due to the fact that wearable devices are generally with the
user at all times, more so than mobile technology. Whilst smartphones can have different app settings for work and home, wearable devices at this time cannot make this distinction.

An article in Forbes suggests that the Apple Watch could lead to BYOW (Bring Your Own Wearable) becoming a common situation (Press, 2015), and it was discovered in 2015 that 54% of companies supported BYOW and a further 40% planned to support it in the future, leaving only 6% without plans to support BYOW (Salesforce.com inc., 2015).

In conclusion, Work-Home Interference is known to be detrimental to health, wellbeing and productivity of the people affected by it. Studies show that mobile computing, especially smartphones contribute significantly to this problem. Whilst studies specific to wearable devices do not exist, it may be suggested that wearable devices may contribute even more than smartphones, due to the fact that wearable devices are to be worn all the time.

2.7. Summary

This section reviewed a large amount of the literature currently available with respect to wearable technology. In section 2.1 wearable technology was defined as “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”, by combining definitions from a number of sources. Section 2.2 enumerated the different types of wearable technologies that currently exist (or have existed), grouped by interface type (supporting technologies were discussed in 2.2.7). The fields of use for wearable devices were discussed in section 2.3, separated in to five subsections.

Section 2.4 investigated the research into wearable usability, and other usability studies that may be extended to wearable devices. The motivations behind the adoption and continued use of wearable devices was discussed in section 2.5, and the possible impact of wearable devices on work-home interference was covered in section 2.6.

This literature review will be used in all three deliverables. Firstly, the literature will be enfolded with the usage and motivational models to validate them in sections 7.3 and 7.4 respectively. The literature found in this review will also be used in the creation of a taxonomy, as described in section 3.

It is worthy of note that a significant amount of literature does not exist for some key areas. One such example is a lack of research into overarching design guidelines for wearables. Guidelines for individual wearables exist, but no guidelines for classes of wearables exist.
3. Taxonomy

3.1. Introduction

This section (section 3) details a taxonomy for the classification of wearable technologies, and the method of its creation. The literature review in section 2 provided the basis for a taxonomy to answer the research question “What are wearable technologies (wearable devices)?” posed in section 4.1.2.1. A definition for wearable technology is provided in section 2.1, but this taxonomy provides more depth.

Wearable technology encompasses a number of very diverse technologies, and it is difficult to determine what is and is not a wearable device. This taxonomy allows classification of said devices, allowing both a method to determine whether a device is a wearable device and a way to compare different wearable devices in a standardised way.

This taxonomy assists the answering of the other two questions, as it is difficult to study the use and user experience of wearable technology without a clear definition. Section 3.2 explains how certain papers found in the literature review (section 2) were selected to be used in the creation of a taxonomy and how the taxonomy was created. The taxonomy is explained in section 3.3 and the subsections describe the dimensions of the taxonomy. Section 3.4 provides a conclusion.

3.2. Methodology

This research looked to a systematic literature review to help gather a number of research studies that relate to wearable devices. The literature found during the literature review (section 2) was used to create this taxonomy. There were a large number of research papers studied, and not all were relevant to this taxonomy. To be considered, these papers had to meet the following criterion:

- The paper must describe a wearable
- The paper must have passed peer review (i.e. published in journal or conference proceedings)

This search yielded 210 results. 135 of the results did not meet the above criteria, leaving 75 papers (and therefore, wearable devices) to be used in the creation of the taxonomy (it should be noted that some sources contained multiple wearable devices). Some other wearable devices
The taxonomy method proposed by Nickerson et al. (2013), as shown in Figure 1, was used as a basis for creating this taxonomy. This method was chosen due to the dual methods that may be applied. Nickerson et al. (2013) describes both a conceptual-to-empirical method and an empirical-to-conceptual method that may both be used in the creation of a taxonomy. In this case, the conceptual-to-empirical method was used to create a basic taxonomy and then the empirical-to-conceptual method was used to revise the taxonomy. This method was simple to apply and appears to have been effective.

The distinctive aspect to the method used is the classification of attributes within dimensions. Nickerson et al. (2013) states that the attributes in each dimension should be both collectively exhaustive and mutually exclusive. It was decided for this taxonomy that the attributes within some dimensions should not be mutually exclusive. Some wearable devices have multiple inputs and outputs which may both be described as “primary”. In addition, some wearable devices have multiple parts, which are to be worn on separate parts of the body.

The resulting set of papers that fitted the aforementioned criteria were analysed and common attributes of the wearable devices that emerged were noted. These themes were further tested as a categorisation method against the wearable devices and by iteration a classification method was developed.
3.3. Findings

As part of the systematic literature review Appendix A shows the various literature that has been analysed by this research. This section will provide various insights into the dimensions and attributes that emerged.

Augmented reality is also an emerging field in wearable technology. The Microsoft HoloLens (Microsoft Inc., 2015b), when released in 2017 is designed to make augmented reality mainstream. Google Glass (Google Inc., 2015c) was also intended to do this, but did not succeed and never became available to the general public. Augmented reality has been investigated for use in the workplace in 2006 as part of the WearIT@Work program by the European Commission (Boronowsky et al., 2006). Many other different wearable devices exist. One of the more unusual wearable devices prototyped involves placing RFID tags into false fingernails which may then communicate with other devices (Vega and Fuks, 2013).

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute</th>
<th>Possible Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Input and Output</td>
<td>Tactile, Biofeedback, Audio, Visual Olfactory (Smell), Natural Movement, Gesture, Augmented Reality, Emotion Geolocation, Context Awareness, Other Devices, and/or Feature Change</td>
<td>Specific to device</td>
</tr>
<tr>
<td>Function</td>
<td>Direct / Supporting Functionality</td>
<td>Specific to device</td>
</tr>
<tr>
<td>Intended primary function</td>
<td>Specific to device</td>
<td>Dependent/Not Dependent</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Fashion</td>
<td>Considered/Not Considered</td>
</tr>
<tr>
<td>Social Acceptability</td>
<td>Considered/Not Considered</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Connectivity</td>
<td>WIFI, Bluetooth, etc..</td>
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<td>Operating System</td>
<td>Android, iOS, etc..</td>
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<tr>
<td>Intended Interoperability</td>
<td>OS, Android, Windows Phone, Windows, Mac OS, Linux, System-agnostic, and/or other.</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>Battery, Rechargeable battery, thermoelectric piezoelectric, solar, etc....</td>
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</tr>
<tr>
<td>On-body Location</td>
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<td></td>
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</table>
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<table>
<thead>
<tr>
<th>Availability</th>
<th>Commercially Available, Under Commercial Development, Experimental or No Longer Available</th>
</tr>
</thead>
</table>

Table 10 - Wearable Technology taxonomy

Based on the literature analysed, Table 1 presents the wearable technology taxonomy. Some of the dimensions (input, output, on-body location and availability) have multiple values, because it is unclear sometimes which value is the primary method. These dimensions did not include a specific set of attributes. Primary input and primary output determine how the user connects with the device, which includes a similar set of possible values for both input and output based on literature analysed. Although a significant number of wearable devices are commercially available, many more wearable devices have been created as prototypes or are under commercial development. Type of availability is highlighted in the Table 1 as a dimension that does not have any specific attributes.

The function of the wearable is an important dimension which includes various distinct attributes. The direct/supporting functionality attribute specifies whether the user interacts with the device directly or not. The intended primary function of the device is important, as the intended function influences the design of the wearable. Dependence is an attribute that describes the wearable devices reliance on another device or system in order to function.

The Aesthetics dimension included a number of attributes that are unique to wearable devices. These include the Fashion and Social Acceptability attributes, which are not always included in design but can have a great impact on a wearable. Google Glass (Google Inc., 2015c) is an example of a wearable designed for consumer use where fashion and social acceptability were not considered. On the other hand, in some environments fashion and/or social acceptability play a minor role (e.g. a workplace where technology is mandated).

The technology dimension highlights various attributes of a wearable interacting with other devices. Connectivity, Operating System, Intended Interoperability and Power are all attributes of the technology dimensions. Connectivity, OS (Operating System) and intended interoperability are important with respect to the wearable interacting with other devices. The method of powering a wearable is also important, as the wearable may need to be recharged.

On-body location is important as a dimension, due to the fact that similar devices can have different locations where they are to be worn. For example, a fitness tracker could be designed to be worn on the wrist or the ankle.
Availability is especially important when acquiring a wearable. Only wearable devices that are currently available may be purchased. Wearable devices under commercial development are likely to be available soon, and the person acquiring a wearable may decide to wait until a wearable in this category is available. Experimental or no longer available wearable devices are not likely to be available to the public in the foreseeable future.

3.3.1. Dimension 1: Primary Input and Output

Wearable devices may be classified by their input and output methods. Only sensor-based input and outputs will be considered in this section, as inter-device communication methods do not provide a great deal of information about the wearable and are not always static (many Android Wear devices now support Wi-Fi, even if they did not at the time of purchase). This section covers two dimensions in the categorisation method. The primary method of input may be different to the primary method of output for a device, therefore primary input method is a different dimension to primary output method. The following values were identified from the literature reviewed for Primary Input and Output.

**Tactile**

Tactile input is a very common method of input, as many devices have touch-sensitive screens and/or hardware buttons. Tactile input is defined as any input based on touching the device with an intent to interact (e.g. using a touch screen, using a stylus, pressing a hardware button) Tactile output (vibration) is also a common method of output in wearable devices.

The Huawei Watch (Google Inc., 2016b) is an example of a wearable that uses both tactile input and output. The Huawei Watch can accept tactile input through its touch screen and may deliver tactile output through vibration.

Tactile input is not restricted to simple touches, one prototype device allowed panning, tilting and twisting of the screen in addition to a “click” method, which was different from tapping the screen (Xiao et al., 2014).

**Biofeedback**

Biofeedback is purely an input mechanism, as wearable devices are non-living. Biofeedback has been collected by devices in the form of heart rate, electroencephalography (brain activity), electrocardiography (electrical activity within the heart), galvanic skin resistance (sweat) and other methods.
Heart rate is one of the more common forms of biofeedback collected by wearable devices. The Fitbit Charge HR (Fitbit Inc., 2015) is one such wearable. A number of smart watches also provide the same feature (Google Inc., 2016b, Apple Inc., 2015c).

**Audio**

Audio output has been a feature of mobile technology for a long time, starting with mobile cassette tape players moving on to smartphones. Audio input has been less common, as recognition of the spoken word is challenging in a mobile environment.

Audio input and output are useful, as they leave the user’s eyes free. This allows the user to interact with the device while moving around. Most wearable devices appear to use audio input and output in addition to other methods of interaction, rather than depending solely on audio.

Some wearable devices, such as the Samsung Gear S2 (Samsung, 2016), provide both audio input and output whereas some comparable devices, such as the LG G Watch R (LG Australia, 2016), only have either audio input or output.

**Visual**

Visual interaction is arguably the most common form of output from wearable devices (via a screen). Visual input by way of cameras is less common. One of the more common examples of visual input is Google Glass (Google Inc., 2015c), where a head-mounted camera allowed visual input to the system. Visual output is very common in wearable devices. Nearly all wrist-mounted and head-mounted wearable devices use visual output in some form.

**Olfactory (Smell)**

Olfactory input and output have not yet been developed to any extent, but it is a possible source of input and output. Olfactory sensors can provide an extra source of input that can aid context awareness. For example, a smell of grass might inform the system that the user is outdoors, or a smell of hot oil may inform the system that the user is cooking (or that their cooking is burning). Olfactory output systems are in their infancy but have great possibilities in the future. It is believed that smell is the most powerful trigger in the human memory. Therefore, smell outputs could assist the user with memory amongst other things.

**Natural Movement**

Natural movement is a separate category from gesture-based movement. Natural movement occurs when the user is not consciously interacting with the wearable. Obviously, natural
movement cannot be used as an output from a wearable. The most common examples of natural movement as an input are found in fitness trackers (Fitbit Inc., 2015, Jawbone Inc., 2015). The natural movement detected in the act of taking a step is detected and the number of steps taken is counted.

**Gesture**

A gesture differs from natural movement in that the user is directly interacting with the wearable. This is also purely a form of input. Some gesture-based inputs use gyroscope and accelerometer systems to detect certain movements. When the wearer of a LG Watch Urbane (Google Inc., 2016c) moves their hand from a resting position (at their hips) to their chest height and rotates their wrist so the watch is facing them, the watch accepts this as a wake command. The user may also flick their wrist to move between notification cards on the watch. Some head-mounted wearable devices accept gestures when noticed by a camera, although usually the system must be informed that the user’s gesture is a command to avoid accidental commands (Keaton et al., 2005).

**Augmented Reality**

Augmented reality is the process of creating an “overlay” over the real world. This information is usually presented to the user by specialised eyewear. Augmented reality is purely an output method. Two commercial augmented reality systems are Google Glass (Google Inc., 2015c) and Microsoft HoloLens (Microsoft Inc., 2015b). It is worthy of note that many AR systems have been described as “clunky” and unfashionable, although new innovations in technology are aiming to change this (Ingraham, 2016).

**Emotion**

Whilst computers are incapable of true emotion, some systems exist that are designed to mimic emotion. This makes emotion both an input and output source for wearable devices. A prototype system to develop clothing that adapts to show the user’s emotional state has been developed (Dastan, 2016). Few (if any) emotional wearable devices are commercially available at this time.

**Geolocation**

Geolocation is primarily an input and consists of using multiple inputs to determine the location of the wearable (and through that, the user). Many inputs, such as Wi-Fi addresses, GPS signals and mobile phone tower signals may be used to do this. It is worthy of note that indoor location
awareness is a form of geolocation, although on a smaller scale. Although directions and maps are based on geolocation input data, the output is delivered to the user via a different input/output (usually visual/audio). The unusually named Haptic Sandwich device is an example of a device that uses geolocation (Spiers et al., 2015). Many wearable devices do not have their own geolocation systems, but rely on geolocation data from another device, such as a mobile phone. This does not mean, however, that their main input cannot be location information.

**Context Awareness**

Context awareness is when a device uses multiple sources of information to determine how to act in a way to be most useful to the user. This is an output from the device to the user. Context awareness is important to wearable devices as peripheral interaction, also known as “glanceability”, requires the system to provide only the data needed and relevant functions. In addition, the input and output sources of wearable devices are usually limited. The Huawei Watch (Google Inc., 2016b), the LG Watch Urbane (Google Inc., 2016c) and other Android Wear devices make use of the Google Now system (Google Inc., 2015b) to attempt to provide context aware information to the user.

**Other Devices**

Some devices, usually devices that play a supporting role, do not receive input and/or output from the user. They rely on other devices to do this. For example, a prototype of a power-generating jacket (Stark, 2012) arguably receives no input from the user (although it relies on body heat) and provides only power. It cannot interact directly with the user, but it can power other devices which may. Another example is the Emendo system (Radevski et al., 2015). The Emendo system gathers brain activity, but the data is not available to the user via the wearable. The data is used to increase productivity through task and break scheduling. The Finger Sleeve (Surale, 2015) works the other way around. It does not receive information directly from the user but provides haptic feedback to the user to assist with navigation.

**Feature Change**

Feature change is an unusual method of input and/or output. It is used to describe wearable devices that interact by changing an aspect of the wearable (e.g. shape, colour, etc…). The Haptic Sandwich (Spiers et al., 2015) and emotionally responsive clothing prototypes (Dastan, 2016) are examples of where the primary output is a change in the shape of the wearable. Colour-changing wearable devices exist in a T-shirt for runners that changes colour with respect
to the amount of running they do, and a shirt for boxers that shows where punches have occurred (Ferraro and Ingaramo, 2014). No wearable devices in this study were found that use a change of the wearable’s features as an input, although such a device is possible.

### 3.3.2. Dimension 2: Function

Wearable devices may be classified by the functions that they perform, and what role they are designed to play. For example, a heart rate monitor designed to be worn while exercising differs greatly from a wearable ECG machine in a hospital, although their basic functionality is almost identical. In addition, smart fabrics and other systems are unlikely to interact directly with the user, but they are still wearable technology.

#### 3.3.2.1. Direct / Supporting Functionality

Direct functionality occurs when the device interacts directly and intentionally with the user. For example, a smart watch interacts directly with the user, as it accepts intentional input from the user and delivers an output that the user must logically comprehend (i.e. not instinctive).

Devices that provide a supporting functionality do not interact directly and intentionally with the user. A heart rate monitor (chest mounted) (Zheng et al., 2016) is an example of indirect functionality. The device gathers data without conscious interaction from the user and does not provide output in a meaningful manner to the user. Any output is provided by another device that accesses the data.

Other wearable devices can be useful in supporting the basic functions of other wearable devices. One such wearable experiments with incorporating thermoelectric heat generation into clothes (Stark, 2012). This wearable supports other wearable devices by providing power.

#### 3.3.2.2. Intended primary function

When a wearable device is developed, it has a primary function which it is intended for. This primary function is usually based on the functionality that distinguishes the wearable from other types. Arguably, the intended primary function of a smart watch is to tell time. All other functions (while possibly more useful) are secondary.

For example, the Haptic Sandwich (Spiers et al., 2015) clearly has a primary function of assisting navigation.
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When a device has a large number of uses, such as the Microsoft Hololens (Microsoft Inc., 2015b), it can be difficult to determine the primary function. In such a case, a broad definition of what the device provides may be used. In the case of the Hololens (Microsoft Inc., 2015b), its primary function is to provide augmented reality.

3.3.2.3. Dependence

Some wearable devices are able to operate independently, whereas other wearable devices require connection to another device for the majority of their functionality.

Many smart watches (Google Inc., 2016b, Apple Inc., 2015a) are dependent wearable devices, as they require a connection to a mobile phone for the majority of their functions.

The SmartHat system (Teizer, 2015) is a good example of an independent wearable. The sole purpose of SmartHat is to provide collision warnings and it does that without requiring a connection to another device.

Activity trackers, such as the Fitbit (Fitbit Inc., 2015), can be difficult to categorise as they require connection to a device as they cannot store data for a long period of time or perform analysis of their data. They would generally be classed as independent wearable devices although many devices provide limited data storage because the basic function (step tracking) may be performed without a device.

However, should the fitness tracker have no means of displaying the steps taken (by a set of lights or by a display) the wearable would become dependent, because it cannot communicate its findings to the wearer without an external device.

3.3.3. Dimension 3: Aesthetics

Aesthetics is an important part of wearable design where wearable devices are not mandated to be used. Some wearable devices are designed to be fashion statements and socially acceptable in everyday use. Some systems are not. This distinction is important and can be used as a means of classifying wearable devices.

3.3.3.1. Fashion

Although wearable devices serve a technological purpose, some wearable devices are designed to be fashion accessories as well. This dimension is binary, determining whether fashion has
played a significant role in the design of the wearable, not in whether the wearable has become fashionable.

The LG Urbane (Google Inc., 2016c) provides an example of such a wearable, as it is highly fashionable, although it is primarily a smart watch and not a fashion accessory.

From another perspective, wearable technology can be created starting from a fashion accessory. Jewellery has been investigated (Silina and Haddadi, 2015), as have RFID tags embedded in false fingernails (Vega and Fuks, 2013).

3.3.3.2. Social Acceptability

Although wearable technology is useful, it must be socially acceptable. For example, although smart glasses may be fashionable and useful, the fact that they usually contain an always-on camera provides privacy concerns (Ge, 2016). This impacts the social acceptability of such wearable devices. In addition, a wearable must be comfortable to be socially acceptable. As is the case with the fashion dimension, this dimension is binary with respect to whether the social acceptability of a device has been considered in the design of the wearable.

Overt wearable devices, while not unfashionable, can also affect social acceptability of a wearable device (Puikkonen et al., 2011). Some wearable devices have been designed to minimise disruption, to increase their social acceptability. One such example is the e-SUIT (Toney et al., 2002), which appears to be a normal suit jacket, but has inconspicuous lights on the cuffs to attract the wearer’s attention when needed.

3.3.4. Dimension 4: Technology

Due to the unique challenges and opportunities provided by wearable devices, they can develop innovative ways to interact with current technologies. This interoperability with other technologies provides another means of classification.

3.3.4.1. Connectivity

Wearable devices use a variety of communication methods. Although the majority of wearable devices use one communication method, some can use multiple methods of communication. The LG G Watch is an example of such a wearable. It can use Bluetooth or Wi-Fi to connect to other devices (LG Australia, 2016). A non-exhaustive list of possible values is as follows:
Bluetooth
- Wired
- Wi-Fi (802.11)
- ZigBee
- Mobile network (GSM etc…)
- Wi-Max

GPS functionality is not included in this section, as it is included in the primary input/output system (geolocation) and it is not an actual means of connectivity.

3.3.4.2. Operating System

Every wearable has an operating system. Operating systems range from the very simple in activity trackers such as the Fitbit through to the very complex such as WatchOS, which runs on the Apple Watch (Fitbit Inc., 2015, Apple Inc., 2015a).

The operating system of a wearable is very important, as it determines the functionality of the device. This makes it a useful dimension to consider when classifying a wearable.

3.3.4.3. Intended Interoperability

Interoperability is an important factor in wearable technology. Although several devices are interoperable with all systems (system-agnostic), this is not true for all. Android Wear devices are intended solely to operate with Android OS devices, just as Apple Watches are designed to only communicate with iOS devices (Apple Inc., 2015c, Google Inc., 2016b). Whilst the aforementioned devices are able to communicate with the other operating system, they are not able to operate to their full potential.

A device may be classed in this section as one of the following (this list is not exhaustive):

- iOS
- Android
- Windows Phone
- Windows
- Mac OS
- Linux
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- System-agnostic

3.3.4.4. Power

Although many wearable devices have internal batteries and charge through connection to a charger, this is not true for all. Some wearable devices also consider new ideas of power generation. One such wearable uses thermoelectric generation in a jacket to generate power. Very little power is generated, but new sensors combined with Bluetooth Low Energy require very little power (Stark, 2012). Other systems such as piezoelectric generation (Gonz et al., 2002) have been considered but are not yet commercially available.

Some wristwatches use the movement of the user’s wrist to generate power (Rolex, 2016), but few smart watches take advantage of this technology.

3.3.5. Dimension 5: On-body Location

Wearable devices are worn on the body by definition, but the position where they are worn on the body differs between devices. This is a useful method for categorisation.

For example, both the Fitbit and the Nike + iPod are activity trackers and are similar in all other categories. Their main difference is that the Fitbit is worn on the wrist and the sensor for the Nike + iPod system is worn in the shoe of the wearer (Apple Inc., 2015c, Fitbit Inc., 2015).

3.3.6. Dimension 6: Availability

Although many wearable devices exist, not all of them are available for purchase. This dimension is different to the other dimensions, in that a wearable’s classification may change over time. In theory, a wearable could start as experimental, then start being developed for commercial sale. Once released to the public, it would move into the category for being commercially available. Once new technology makes it obsolete, it would move to the category for products that are no longer available.

The taxonomy only provides for the aforementioned four values for this dimension.

It was considered that this dimension be split into “commercial” and “non-commercial”, however it was decided that wearable devices could also move between these classifications over time.
It is important to know the availability of a wearable for many people. A person interested in commercially developing a wearable would want to know which wearable devices have been developed, and which ones have been made available for sale (or will be soon). An organisation would be interested in which wearable devices are available or will be available soon, not in wearable devices that have no prospect of being available for sale.

**Commercially Available**

For the purposes of clarification, a commercially available device is a device that may be purchased (in-store or online). These devices include the Fitbit, Apple Watch and Huawei Watch amongst others (Fitbit Inc., 2015, Apple Inc., 2015a, Google Inc., 2016b).

**Under Commercial Development**

A device under commercial development is a device that is not yet available for sale but has been announced. One example of such a product is the Microsoft Hololens, which has been announced but is not available for sale at the time of writing (Microsoft Inc., 2015b).

**Experimental**

Experimental devices are devices which are not commercially available, with no evidence to suggest that they will be available in the future. Many prototype devices fall into this category, such as the SensVest and the RFIDGlove (Knight et al., 2005, Muguira et al., 2009).

**No Longer Available**

No longer available devices are devices that were once available or under development, but are not currently for sale. The device must also not be expected to be available in the near future (or it is to be categorised as “under commercial development”).

One of the most recent examples of a product in this category is Google Glass, which was sold to a small number of people but was then removed from sale (Google Inc., 2015c).

### 3.4. Summary

In this section, a method for classification of wearable devices was proposed. This taxonomy helps identify key features of a wearable that impact on its usage.

The following dimensions may be used to classify wearable devices:

- Primary input: Main method of the user providing instructions/information to the device
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- Primary output: Main method of the device providing information to the user
- Direct/Supporting Functionality: Whether the device interacts directly with the user or interacts via another device
- Intended primary function: The intended purpose of the device
- Dependence: Whether the device can provide the majority of functions without another device
- Fashion: Whether fashion was considered in the design
- Social Acceptability: Whether social acceptability was considered in the design
- Connectivity: How the device connects to networks
- Operating System: The operating system the device uses
- Intended Interoperability: Which kind of systems the device is designed to operate with (e.g. PC/Mac)
- Power: How the device is powered
- On-body Location: Where on the body the device is worn/carried
- Availability: The status of the device in the development life cycle

The large number of dimensions are necessary due to the diverse nature of wearable technologies. A blank table that could be used for taxonomical classification is shown in Table 8.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute</th>
<th>Value</th>
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<tbody>
<tr>
<td>Primary Input and Output</td>
<td>Primary Input</td>
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</table>

Table 8 - Blank Taxonomy Table
4. Research Design and Research Methodology

This section explains the design of the research and its methodology. The results of this research (section 5) provided the data necessary to create the models (sections 6.2 and 6.3) which are two of the three deliverables from this research thesis.

In this section, the questions that the research is expected to answer (section 4.1) are discussed, as well as the methodology used to answer these questions (section 4.1). A number of methods were considered in the research design, but grounded theory was decided upon (section 4.3). Two methods of data collection are used in the research: qualitative interviews (section 4.4) and document analysis (section 4.4.4). The methods used for analysis are explained (section 4.5.3) and the constraints of the thesis are noted (section 4.3).

4.1. Research Objectives and Questions

In this section, the research questions are defined. The methodology Section 4.1) was developed with these questions in mind, especially with respect to the qualitative interviews conducted (section 4.4). Section 4.1.1 explains the primary research question, and Section 4.1.2 enumerates the secondary research questions, which are questions whose answers facilitate the answering of the primary research question.

The three secondary research questions align with the three objectives of the research. The first objective is to create a definition of wearables (in the form of a simple definition and a taxonomy). The second objective is to determine how wearables are currently used, in the creation of a relational model between user experience and fields of use. The third and final objectives is to understand the motivations behind the use of wearable devices, which are to be shown in a hierarchical model.

4.1.1. Primary Research Question

The primary question of this research is:

“What elements affect the adoption and usage of wearable technology?”

Many wearable technologies exist, and there is no clear understanding as to why users use wearable devices and how they use wearable devices. Understanding this will allow wearable devices to be created that are appealing (facilitating adoption) and useful (usage/user experience).
Wearable devices are a relatively new and expanding field, which makes understanding why and how wearable devices are used an appropriate question.

4.1.2. **Secondary Research Questions**

4.1.2.1. **What are wearable technologies (wearable devices)?**

To study wearable technologies, the term must be fully defined. A number of definitions exist, but they do not sufficiently define what wearable devices are. Whilst it may seem obvious, there are a number of possible ambiguities. A mobile phone is carried on the body, but would it be considered a wearable? Would wearing headphones connected to the mobile phone make it a wearable? Is a device carried but not affixed to the body wearable or not? The definition of wearable technologies must be formalised to allow the field of study to be clearly defined. Two deliverables are to be created to answer this question. Firstly, a simple definition of wearable technology is to be created. Secondly, the creation of a taxonomy to classify wearable devices extends and clarifies the definition of wearable technologies.

4.1.2.2. **How are wearable devices currently used?**

As wearable devices are a relatively new technology, there is little research into how wearable devices are currently employed in real world situations (in contrast to trials). Wearable devices have many varied uses, and many are multi-purpose. The answer to this question gives designers of wearable devices a greater understanding of the fields of use their wearable devices are likely to be used in. This would show how parts of the user experience affects different fields of use, thus explaining how user experience design affects how wearable devices are suited to different fields of use.

4.1.2.3. **Why do users use wearable devices?**

Wearable devices are becoming more common, but the motivations for generally using wearable devices are not clear. This question is asked because, if wearable devices are to be useful, users must be motivated to use them. This question is twofold. Firstly, why do users decide to purchase a wearable and start using it (unless wearable use is mandated)? Secondly, once the user has a wearable, what influences them to keep using it? Understanding why users use wearable devices allows wearable devices to be made that appeal to these motivations. The answer to this research question should explain which factors make users begin to use wearable
devices and what compels users to continue to use wearable devices (and if there is any difference between the two sets of reasons).

4.2. Techniques For Data Collection

The research questions (section 4.1) were answered using the methodology described in this section. In this section the two methods of data collection, interviews and document analysis are discussed (in that order). These methods are covered in depth in sections 4.4 and 4.4.4 respectively. This section also explains the process which was used, based on the approach suggested by Eisenhardt (Eisenhardt, 1989), albeit slightly modified.

Grounded Theory, Multi-grounded Theory, Actor Network Theory (ANT), Action Research, and Ethnography were considered as methods to use in this research project, and they are summarised below. The concept of the IT artifact (5 different views of technology) is also discussed in the context of analysis.

The taxonomy (see section 3), was created from the information in the literature review (section 2) using an iterative method not related to grounded theory (Nickerson et al., 2013). The details of the methodology used to create the taxonomy may be found in section 3.2.

Grounded theory (Corbin and Strauss, 1990) involves collection of data and coding of the data at the same time of the analysis of the data. This can be useful in the research proposed, as it allows for possible common threads in usability issues to be detected and investigated in early research.
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All information should be constantly compared against other information, which allows further investigation to be more targeted. Grounded theory also states that theories should be generated from concepts, not directly from raw data.

Grounded theory looks at concepts and actions, regardless of actors. The data analysis is separated by action/concept, not by source. This allows events/concepts that are common to be easily identified and allows outlying data to be discarded. Grounded theory is the core method used in this research project. As wearable technologies are a new and emerging area, research in this area is scarce. Grounded theory supports examining an area with a naïve approach, which is the approach required due to the scarcity of research.

Multi-grounded theory as described by Adamopolous (2014) is a variation of grounded theory. In Grounded Theory, literature is enfolded into the result near the end of the process. Multi-grounded Theory involves enfolding literature at multiple steps during the process. Due to the rapid expansion of the wearable technology field, this may be counted as a strength of multi-grounded theory.

Actor Network Theory (ANT) (Law, 1992) is another tool that may be used for data analysis. ANT focuses on the relationships between entities (referred to as actors). An entity can be any object that performs an action or has an action performed upon it. There is no distinction between different types of actors (e.g. humans, computers, objects) (Law, 1992). As this research intends to study relationships between wearable technology and its users, ANT may be used to create a model of their interactions.

The concept of the IT artifact (Orlikowski and Iacono, 2001) was considered for use (but was not used) in data analysis. This concept supports five views of technology. These views are tool, proxy, ensemble, computational and nominal. Multiple views could be used in data analysis. The tool view can be used, as wearable devices process information and can be used to increase productivity. The proxy view can be used as the perception of wearable devices is likely to have a significant impact on their usability. The ensemble view of technology can be used with respect to wearable devices, as they can be ubiquitous, similar to an embedded system. The computational and the nominal views are not highly relevant to usability research in this case. The computational view views technology as an algorithm or as a model in itself. The nominal view omits technology.
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Action Research (Myers, 2019) aims to solve problems of users in real-world situation. The purpose of this research was to identify and explore issues, not solve issues. Therefore, Action Research was not suitable for this research project.

Ethnography (Myers, 2019) aims to share the lives of the people who are relevant to the phenomenon. In this case, this was impractical due to the fact that the participants were individuals (rather than a community) and the field of research was narrow. An ethnographic approach is not appropriate in this case.

The methodology of this research consists of a number of interviews and document analysis of available data (e.g. blogs). Analysis of the interviews and documents, in addition to a review of current literature determined how the resulting information answered two of the three research questions: “How are wearable devices currently used?” and “Why do users use wearable devices?” The third research question was answered only using peer-reviewed literature, and the methodology for it may be found in section 3.2.

The research began looking for participant using wearable technology. After initial interviews it became difficult to recruit participants. This difficulty was assumed to be due to wearables being in the early adopter stage or at the beginning of the early majority stage (Rogers, 2010). To increase the population, documents describing peoples experience with wearables were also included.

The interviews focused experiences with wearable technology in daily life. The interviews attempted to ascertain what the participants find easy to use in wearable devices and where they experience difficulty. Twenty interviews were conducted. No further interviews were conducted due to data saturation being reached (final 2 interviews did not yield any new topics). Further information about the interview method and participants may be found in section 4.4.

There were 229 documents investigated to find instances where the authors have interacted with wearable technology. These documents were reports of personal experience with wearable devices, not marketing information. The criteria for selection of the documents can be found in section 4.5.

The case study approach is described as “a research strategy which focuses on understanding the dynamics present within single settings”(Eisenhardt, 1989), and “typically combine data collection methods such as archives, interviews, questionnaires, and observations” (Eisenhardt, 1989). In this case, the data collection methods used were interviews and document collection.
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The case studies ascertained in the interviews and document analysis were analysed to develop an understanding of the motivations behind using wearable devices and the uses of wearable devices. The achievement of these two objectives (answering two research questions) was done using an 8 step process developed by Eisenhardt (1989), due to the case study data to be analysed. The process involves multiple data sources and analysis by both within-case and cross-case analysis to develop hypotheses. The process used is iterative as more data is collected and hypotheses are refined.

![Figure 3 - Process by Eisenhardt on Grounded Theory - Modified (Bruno, 2011)](image)

The Eisenhardt process contains eight steps, which are described below.

The first step is “Getting Started”, in which the focus of the research is to be explicitly defined. This determines the data to be gathered during the research. The research questions define the focus of the research in this case.

The second step is “Selecting Cases”. Selecting cases involves finding samples from the population to investigate. This was twofold in this research, as cases were selected from documents and from prospective participants.

The third step, “Crafting Instruments and Protocols”, is used to determine how the data will be collected from the samples. Interview structures were created in this state in this research.
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Steps four, five and six are an iterative process, allowing refining of hypotheses created by the theoretical sampling concept in grounded theory.

The fourth step is called “Entering the Field”. In this section, the data collection occurs. Interviews were conducted and documents were collected in this stage.

The fourth step involves “Analysing Within-Case Data”. This step looks at each case/data piece individually and attempts to codify it. In this research, open coding was performed on each document and interview transcript.

The fifth step, “Searching for Cross-Case Patterns” involves finding similarities and differences between cases. This research performed this step by standardising the coding used (axial coding), allowing common themes between cases to emerge.

The sixth step is called “Shaping Hypotheses”. The previously analysed data is used in this step to create hypotheses based on the information provided by the data analysis (selective coding). In this case, two models (Usage and Motivation) were created.

In the seventh step, “Enfolding Literature”, existing literature is enfolded into the research. The models developed in this research were matched against existing research, to assess whether they were in accord with previous research or contradicted some research (and if so, why).

The final step is called “Reaching Closure”. Once theoretical saturation has been reached (i.e. when very little is to be learnt by further data collection/analysis), the process is to end and present the results of the research. This thesis is the result of this step.

As shown in Figure 3, this process as originally designed by Eisenhardt (1989) was slightly modified in this research, as was done by Bruno (2011), to include the grounded theory analysis and the iterative nature of the analysis performed. As participants were being sourced, other interviews were being transcribed, and open coding occurred, as shown in part (a) of Figure 3. This was done to expedite the process, especially due to the difficulty of finding participants.

Additionally, as shown in part (b), axial coding (creating concepts) also occurred during the process of data collection (part (a) in Figure 3). This allowed the creation of concepts to occur while more data was being collected.

Finally, part (c) depicts the fact that axial coding and selective coding (creating themes) occurred simultaneously. It is worthy of note that open coding was fully complete before selective coding.
occurred. Themes started to emerge with axial coding but were not finalised until axial coding was complete.

4.3. Research Approach

A number of existing theories have been considered, as these theories may have provided a framework which the research could be based on. The majority of these theories rely mostly on quantitative data, such as survey data. The data in this research was collected via interviews, leading to the collection of qualitative data, requiring an interpretivistic approach (not supported by the considered theories). As this research was exploratory, Grounded Theory (Corbin and Strauss, 1990) was chosen as the method to be applied to create a new theory. Eisenhardt (1989) provides a method for the creation of a model from the data collected in this research project.

The theories considered in this section include the Unified Theory and Acceptance (Venkatesh et al., 2003) and Use Of Technology model 2 (UTAUT2) (Venkatesh et al., 2012), the Diffusion of Innovation (Rogers, 2010), the Theory of Planned Behaviours (Ajzen, 1985, Ajzen and Fishbein, 1980) and the Actor-Action-Artifact model (Burton-Jones and Straub Jr., 2006). These theories were considered as ways to conduct and explore the research aims, but they were not used. Many of these theories (UTAUT, UTAUT2, Diffusion of Innovation) focused on the adoption of technology but did not focus on the usage of technology once it has been adopted.

UTAUT2 (Venkatesh et al., 2012) is a revision of UTAUT (Venkatesh et al., 2003). They both supersede the Technology Acceptance model, which was originally considered. UTAUT was developed by assessing eight prominent models and creating a unified model. This unified model was then validated. UTAUT2 differs from UTAUT in that UTAUT focuses on situations where technology use is mandated (e.g. an organization) whereas UTAUT2 focuses on consumer-driven use (e.g. deciding to purchase and use a fitness tracker). UTAUT2 considers a number of factors, and investigates how age, gender and experience can impact on the strength of these factors. In the end, UTAUT2 developed 5 hypotheses and tested them. One hypothesis had to be modified slightly, but all other hypotheses were supported. This model may be useful to help understand the underlying influences on the User Experience of wearable devices. Furthermore, UTAUT2 may also help to explain why certain groups of people are more likely to use wearable devices than others.

The Diffusion of Innovation theory (Rogers, 2010) covers the adoption of any innovation (technological or not). Diffusion is defined as “the process by which an innovation is
communicated through certain channels over time among the members of a social system”. This theory looks at the decision by individuals and groups to accept/reject the innovation looking at a number of factors about the innovation, the communication of the innovation, the importance of time (the adoption curve of technology) and the social system. This theory is useful with many technologies, especially when adoption is voluntary, and the benefits are not known by the users.

The Theory of Planned Behaviour (Ajzen, 1985, Ajzen and Fishbein, 1980) is based on a premise that an individual’s intention to perform an action is based on two factors. These factors are their evaluation of the result of performing or not performing a behaviour (referred to as their attitude) and their perception of social pressures to perform or not perform the behaviour. It is acknowledged that these two factors often carry different weights, and the intention to perform a behaviour (and the performance of a behaviour) is stated to be directly proportional to the weighted average of the two factors. The theory states that both factors may be complex. With respect to attitude, the individual may believe in several outcomes from a certain behaviour and may have varying levels of belief in the occurrence of each outcome (behavioural beliefs). The social pressures (also known as the subjective norms) are similar but looks at the beliefs of a certain referent and the motivation to comply with that referent. This theory is strong where the social expectations and the belief in outcomes are known. In this research, these variables are not known and cannot be reasonable estimated. Should these variables become apparent, this theory may be useful when enfolding literature.

The Actor-Action-Artifact model (Burton-Jones and Straub Jr., 2006) proposes that system usage is comprised of three elements. This theory, unlike the previously mentioned theories, is a usage theory. This theory was considered, as the usage of wearable technologies during usage is to be researched (not just the adoption phase). The aforementioned elements are the user, the system and the task to be performed. System usage (by individuals) is described as being “an individual user’s employment of one or more features of a system to perform a task”. The theory is designed to look at rich data collected with binary relationships between a pair of the three element and from a ternary relationship where all three elements interact in one action. Whilst this theory deals with rich data, it is based on quantitative data. Qualitative data is very rich data but cannot usually be handled in the same way as quantitative data.

These theories were investigated to assist in the examination of the case studies in this research and have been used in the enfolding of literature in section 7. In this research, new theories were
generated by applying Grounded Theory (Shackel, 1981) in the process described by Eisenhardt (Eisenhardt, 1989).

### 4.4. Qualitative Interviews

One of the two sources of data, qualitative interviews, is covered in this section. This data source consists of structured interviews with users of wearable technology. In this section, the profile of participants to be interviewed is explained (section 4.4.1) as well as how they will be recruited (section 4.4.2). The basic structure of the interviews is also discussed (section 4.4.3).

#### 4.4.1. Participant Profile

The participants were employed people who have used/use wearable devices (more than activity trackers). Participants with experience with more than one wearable would be preferable. The participants must have some form of employment to show the use of a wearable in multiple fields of use, and they must use or have used a wearable device, so they have a perspective related to wearable use.

A study of user experience with respect to wearable technology shows little difference in gender, therefore the gender balance of participants is not likely to affect the results (Hwang et al., 2015).

#### 4.4.2. Participant Recruitment

A number of methods were used to recruit participants. Participants were recruited through contacts of the researchers that were known to use wearable technology. Requests for participants were also placed in ACS (Australian Computing Society) newsletters and in relevant social media groups. If they were interested, they were provided with a Participant Information statement and a consent form and asked to decide upon whether they wanted to participate after reading the information statement.

Technology companies that produce wearable devices (e.g. Microsoft, Samsung, LG, Apple) were contacted, but were unable or unwilling to assist in providing participants.

#### 4.4.3. Interview Structure

The interviews will be based on responsive interviewing (Rubin and Rubin, 2005). Responsive interviewing is a semi-structured method of interviewing which generally involves asking the participant key questions and generating follow-up questions depending on the response from the
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participant. Although some general follow-up questions are usually prepared before the interview, the interviewer may need to come up with questions during the course of the interview if the interviewee gives an unexpected response.

The “river and channel” approach of responsive interviewing (Rubin and Rubin, 2005) was decided upon as the optimal interview pattern for these interviews. This approach is designed to follow one theme in depth and detail (usability and issues with wearable devices in this case). This approach is also suited to giving examples rather than broad statements. This approach will allow participants to cite issues with usability (both positive and negative).

The approach chosen requires open-ended questions that elicit information from the participant, without restricting the user to short answers. This increases the richness of the information provided.

The questions to be asked are as follows:

- On a day to day basis, which wearable technologies do you use?
- What tasks does your wearable/wearable devices assist you with?
- Can you give me an example where you found a wearable quite useful in a task?
- Can you give me an example where you had trouble with a wearable?
- Are there any tasks that you think your wearable should assist in (where it does not)?
- Are there any areas where you think other wearable devices could be useful?
- Do you have any ideas or comments that you would like to make about wearable devices?

The interviews were recorded, and the recordings transcribed. Where feasible, each interview was transcribed and analysed before any further interviews are conducted (with any participant) to allow for modification to the interview questions to enhance the instrument used to gather the research data.

4.4.4. Interview Limitations

There were a number of limitations that restricted the data collected in the interviews. The two major limitations were the number of participants available and the lack of wearable devices not worn on the wrist.
It was intended that approximately 25 participants would be recruited for this research. Naturally, all the participants had to use a wearable device, preferably more complex than a simple activity tracker. These participants were expected to be innovators or early adopters of technologies, as described in the Rogers Adoption Curve (Rogers, 2010).

Unfortunately, the intended number of participants could not be reached. This decreased the reliability of the results. Twenty was chosen as a goal due to the expected difficulty in recruiting participants, although the smaller number of participants may still provide adequate information and may also allow for deeper analysis (Sandelowski, 1995). In this case, the results showed that theoretical saturation may have been reached. Studies show that theoretical saturation can occur in under 15 interviews (Guest et al., 2006).

Secondly, all participants used wrist-mounted wearable devices. This was a foreseen possibility, but it does affect the generalisability of the results. There are few wearable devices available today that are not wrist mounted. This was a foreseen issue, but while it was still hoped that users of non-wrist-mounted systems could be recruited, this was not the case.

### 4.5. Document Analysis

Document analysis, a source of primary data is discussed in this section. There are three major sources of data for document analysis. The first is Grey literature (section 4.5.1), which is literature that is not peer reviewed, where its accuracy may be called into question. The second is other literature which, while not peer reviewed, may be assumed to be of high quality, such as manufacturer usability guidelines (section 4.5.2).

#### 4.5.1. Grey literature

Due to the rapid pace of change in the field of wearable technology, there is a lack of peer-reviewed information about the uses and User Experience of wearable devices. There is, however, a large amount of non-peer-reviewed information (grey literature) available, which can be used to fill this lack of up-to-date information (Pappas and Williams, 2011, Sadilek et al., 2012).

Whilst the lack of peer-reviewed literature may be viewed as a weakness, the large amount of grey literature shows that there is a large amount of information available. This information, however, has dubious credibility and therefore grey literature must be checked for credibility.
before being included in this research. This section discusses how the credibility of grey literature may be ascertained.

Grey literature provides a useful source of information with respect to uses of wearable devices and the experiences of users. Whilst peer-reviewed information may be more credible, a previous study into grey literature states that meta-analysis (similar to this research) should include grey literature to provide balanced data (Conn et al., 2003).

A number of reputable sites (e.g. well known magazines) provide information useful in determining uses and User Experiences of the users of wearable devices (Tew, 2017, Maddox, 2014).

All grey literature data is taken to be less reliable than peer-reviewed data and is treated as an unstructured interview. It should be noted that interview data is also less reliable than peer-reviewed data.

4.5.1.1. Forums

Forums are areas where a number of people post about a single topic. Forums tend to be less structured than blogs. In addition, blogs may gain credibility over time with quality posts, whereas forums do not generally allow the same credibility to be gained by users. Forums were generally accepted, although the data was not taken as credibly as other sources. Due to the issues above, forum data is to be taken as not credible on a post by post basis. The advantage of forum data is that it is abundant, and consensus can emerge from a large variety of users. This data may be used to find issues that are common among a large number of users.

4.5.1.2. Blogs

A number of people have blogs on the Internet and post their experiences on these blogs. As purchasing and using a wearable is (generally speaking) a new and interesting experience, people post about their experiences. Other studies (Nicholas, 2008, Snee, 2010) have used blog data for social research.

Blogs are a specific form of “grey literature” and are, unfortunately, very difficult to assess the credibility of. Whilst some studies (Kang, 2010) have tried, credibility of blogs is still an issue when highly credible data is required.
Due to this issue, blog data is not usually taken as credible at an individual level. Blog data is abundant, however, which means that a large number of posts from different users can allow overarching themes to appear, as has been done in grounded theory previously (Rubin et al., 2011, Sadilek et al., 2012, Tsai and Chan, 2009).

Blogs can gain credibility by assessing the quality of the posts, the length of time the blog has existed for amongst other aspects. Some blogs may be taken as credible due to these aspects.

4.5.1.3. Online Articles

A number of online publications were used in this study. Online publications are not intrinsically considered as reliable, and three pieces of evidence were taken into account when deciding whether to include the article in the document analysis.

Firstly, in addition to describing a user’s personal experience, the article must not contain obvious bias. Some examples of bias were the article being a testimonial, being obviously associated with the manufacturer of the wearable described (or a competitor) or implying bias from the tone of the language used.

Secondly, the meta-data of the article was considered. Articles were required to have an author and a date of publication as a minimum to be considered. Contact details for the author also added credibility to the article.

Finally, the publisher was investigated. The domain name was looked at for credibility (e.g. forbes.com is reliable, whereas thebestwearabletechintheworld.com may not be). The age of the publication could lend credibility. Whilst wearable devices are relatively new, many articles were in established technology online magazines. Finally, an ISSN for the magazine was considered to lend a significant amount of credibility, although it alone did not automatically include the article in the document analysis.

The aforementioned three aspects were considered in conjunction when articles were either included or not included in the document analysis.

4.5.2. Other literature

Whilst wearable technology is a relatively new field, some literature on wearable devices and their use does exist. Some usability guidelines exist for specific wearable devices, which may be
adapted as general principles (Apple Inc., 2015b, Pebble, 2015, Google Inc., 2015a, Samsung, 2014a, Samsung, 2014b). This literature can be analysed to assist development of guidelines.

4.5.3. Document Analysis Limitations

The analysis of documents revealed a number of limitations on the research. It should first be noted that the documents analysed were not from scholarly sources. Such documents were discussed in the literature review (and were used in the creation of a taxonomy). Secondly, there was no method of clarifying any remarks made in the documents.

Peer reviewed scholarly sources are regarded as reliable sources. Any such documents were discussed in the literature review. In the document analysis various Internet sources were accessed such as blogs, forums, online articles etc... The evidence and views given from these articles are generally anecdotal. This means that the results, whilst they may be believed to be accurate for that user, may not be representative of the general body of users. Therefore, multiple sources must be used for any reliable information to be discovered in document analysis (Conn et al., 2003).

Documents differ from interviews in that the conversation is not in direct response to a set of questions. No documents were written by users explicitly for this research. Although authors of the documents could possibly be contacted for further questions, this can be difficult and such contact would be classed as an interview. The undirected nature of the documents mean that irrelevant data may be included (which must be removed) and relevant data may be lacking context, which can be important. The one-way nature of the conversation means that rectifying either of these issues is rarely possible.

4.6. Data Collection and Analysis

In this section, the analysis of the data collected (as described in 4.1) is explained.

The process developed by Eisenhardt (1989) is to be used as an implementation of the analysis type that is chosen, as mentioned in section 4.1. The process is comprised of the following elements:

- Selecting cases
- Crafting instruments and protocols
- Entering the field (conducting interviews in this case)
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- Analysing within-case data
- Searching for cross-case patterns
- Shaping hypotheses
- Enfolding literature

This process has been slightly modified from its original implementation to fit the analysis method used.

The analysis tool NVivo was used to analyse the data from both document analysis and qualitative interviews. NVivo allows coding of sections of documents. In this case, the documents used were transcripts of interviews and documents found to be useful for document analysis.

Open coding was performed on the documents (including interview transcripts) and a large number of topics were created. These topics were then grouped into concepts, and then themes emerged from grouping of the concepts. Matrix and word frequency queries allowed hypotheses to be created, from which two models were formed. These models were later enfolded with current literature and theories to validate them.

4.7. Ethics

Informed consent was obtained from all participants before interviews were conducted. The participant information and consent form may be found in appendix C. Ethics approval was obtained from the RMIT Ethics Committee (project number 19583).

4.8. Summary

This section explained the design and methodology of the research. A number of methods were considered in section 4.3, and Grounded Theory was chosen as a method to create a new theory. The method of doing this was explained in section 4.1, and this method was used to answer the questions described in section 4.1. Some constraints on the research were acknowledged in section 4.3 and were mitigated as much as reasonably possible. The two data collection methods, Qualitative Interviews (section 4.4) and Document Analysis (section 4.4.4) were explained and the method of data analysis to be used was described in section 4.5.3.
5. Results

In this section, the results from the research described in section 3 are discussed. These results allow for the development of the two models described in section 6. The two models provide answers to two of the three research questions. The usage model (section 6.2) provides an answer to the question “How are wearable devices currently used?”, and the motivational model (section 6.3) answers the question “Why do users use wearable devices?”. Both models are based on the results shown in this section.

In this section, the demographics of the participants and documents are explained (section 5.1). Topics were created from the data. The topics were grouped to form Concepts, and Themes emerged from the Concepts. The results are therefore shown at the Topic (section 5.2), Concept (section 5.3) and Theme levels of abstraction (section 5.4). It should be noted that not all Topics are discussed in this section, due to the number of topics (full results may be found in Appendix B).

The raw data consisted of interviews of users of wearables and online documents about experiences with wearable devices. These data sources have been quoted in this section. Notations of P for participant and D for document are used. For example, P7 means Participant number 7 and D24 means Document number 24.

5.1. Demographics

This section describes the demographics of the two sources of data, participants and documents. It must be noted that the documents in this section are only grey literature, scholarly documents are enfolded in section 7.

The demographic of the participants was quite varied (section 5.1.1). The only common factor amongst all participants was that they used a wearable device in their work and that all devices were wrist mounted. There were a large number of documents analysed (section 5.1.2), mostly articles in online magazines and the like, although blog and forum data was included.

5.1.1. Participants

| Age |
Twenty participants were interviewed. This number is small, due to the difficulty of recruiting participants. Table 9 shows the ages and genders of the participants. Age and gender did not appear to be significant, but they were recorded. Table 10 shows that the majority of participants were from a university or private environment.

To participate, the participant had to use/have recently used a wearable device more advanced than a standard activity tracker (e.g. a smartwatch). The participant profile is explained in more depth in section 4.4.1.
5.1.2. Documents

The documents analysed were categorised into three areas, Articles, Blogs and Forums (see Figure 4). Articles from online magazines provided the vast majority of the data. As Figure 4 shows, a large proportion of the articles were taken from reputable websites, and therefore their data was included in the analysis.

Blog data was treated with a bit more caution, as blogs are not generally subject to a higher level of oversight. Only four blogs met the criteria for inclusion, Salesforce, GSM Arena, GfK Insights and CDP (Salesforce.com inc., 2018, Gsmarena.com, 2018, GfK, 2018, Cambridge Design Partnership Ltd., 2018), as described in section 4.5.1.2.

Finally, Forum data is to be treated with extreme caution, as it is not filtered in any way (with the possible exception of moderation), as mentioned in section 4.5.1.1. No data in this area was taken to be of high quality, but the data was useful to determine how people use their mobile devices. Data from the forums was accepted when multiple forum posts revealed a common thread.
5.2. Topics

Topics are the first level of abstraction from the raw data. The raw data, both interviews and documents were open coded into topics. A large number of topics emerged from the data, and it would be impractical to cover all the topics in this section. The five most prevalent topics were: Fashion, Activity Tracking, Devices, Notifications and Battery, in that order. These topics are covered in more depth in the following sections. A summary of all the topics that emerged may be found in Appendix B.

5.2.1. Fashion

Fashion encompasses the look and feel of a device in conjunction with the wearer’s other garments and accessories. It affects adoption and abandonment of a wearable device. Fashion is used as a method for the wearer to express their identity. Fashion is distinctly different to usability and can conflict with usability. The fact that fashion allows expression means that it carries a social impact, and the social impact of wearable devices is something that users take note of.

A number of sources commented upon the fashionability of their wearable devices. The fashion aspect appears to affect the adoption and the abandonment (or lack thereof) of a wearable.

Usability of wearable devices is important, but it appears that fashion is also very important: “If nobody wants to wear it, is it really wearable?” (#D1). Fashionable wearable devices can even encourage people to buy them: “What got me interested in these was seeing somebody else with one and seeing oh wow, it actually looks like a watch, what I felt at the time. And so, it wasn't, to me, I guess a compromise between a fashion accessory watch and some functionality I wanted” (#P3). Fashion issues in wearable devices appear to fit into two categories, expression and social impact.

Expression of one’s self is a common aspect of fashion. Wearable devices may be seen as accessories, which means they are used as an expression of one’s self when wearing them (i.e. making a “fashion statement”): “Wearable devices are just as much fashion accessories or status symbols as they are devices you count on to perform daily tasks” (#D2).

Social impact of wearable devices is a large factor in usage of wearable devices. It has been assumed that the failure of Google Glass (Google Inc., 2015b) as a consumer product was due to its lack of social acceptability. It is worthy of note that social acceptability and usability can
sometimes conflict: “While there is nothing wrong with cool design per se, and while cool is something to which we should always aspire, cool does not automatically denote usable. In fact, the two can often be in direct conflict” (#D2).

Fashion is referenced in 76 sources (3 of which are interviews), making it a highly prevalent topic.

5.2.2. Activity Tracking

Activity tracking encompasses the ability of wearable devices to detect the movements of the user and determine the activity that they are participating in. This allows the user to quantify the amount of exercise, time spent sitting, duration and quality of sleep, and other metrics about their activity. A number of metrics may be tracked, including location, calories expended, and the activity being performed. Some wearable devices also inform the user about their progress towards certain goals.

Activity Tracking is a topic that occurred regularly both in document analysis and in interviews. This is a common use for wearable technology and a number of wearable technologies, such as the Fitbit (Fitbit Inc., 2015), have activity tracking as their primary use. A number of devices record other metrics with respect to exercise when the user is exercising: “The key thing I use it for is activity tracking. So, count steps [sic] and some things derived from that, like calories and so on automatically. If I go for a run or walk, then I switch GPS on, and it records a bit more about the route” (#P3).

Many smartwatches have step tracking built into their operating systems and many activity-based wearable devices exist. The Apple Watch (Apple Inc., 2015a) also reminds users to stand when they have been seated for a while.

Some users have noted that activity tracking helps them achieve their exercise goals: “So I find that that is fabulous, when I fit my goals, three ten calories a day, 30 minutes of exercise and twelve hours of my stand, so yeah, it helps with that” (#P4).

Activity Tracking is referenced in 72 sources (including 8 interviews).

5.2.3. Devices

There are many different wearable devices, and this topic was created to hold information about the different devices available. Unfortunately, the data in this topic does not provide a great deal
of information. This is due to the fact that the coding of the data just mentions different types of wearable devices, and highlights that there are many different types of wearable devices, from the more common wearable devices currently available: “I’ve got an Apple Watch and that’s it.” (#P1) to the prototypes where wearable devices are under development in interesting environments: “A skin patch that’s thinner than a sheet of paper and can detect subtle tremors, release drugs stored inside nanoparticles on-demand, and record all of this activity for review later” (#D55). A taxonomy has been created in this thesis (section 3) to allow classification of both types of wearable devices.

The significant prevalence of this topic (129 references from 88 sources), does highlight that there are many different wearable devices discussed. The large number and diversity of wearable devices discussed provided the motivation for a taxonomy to be created from the peer-reviewed literature, which may be found in section 3.

5.2.4. Notifications

Many participants and documents mention the ability for notifications (usually from a smart phone) to be viewed and sometimes acted upon from the wearable. This means that the user is not required to access their mobile device every time a notification is received, they may glance at their wearable instead. It also lowers the risk of notifications being missed, as the wearable is always worn. Forty-one sources make note of this, including ten participants.

Many wearable devices (mostly smart watches) connect wirelessly to a smart phone or similar device. They then mirror the notifications that appear on that device (e.g. SMSes, incoming calls, IM messages). The wearable provides a less intrusive way to check notifications (as opposed to accessing a smart phone or similar device): “What I like about the watch is it’s a subtle way to get notifications”; “Just being able to, at a glance, even when I’m not specifically going to look it up just to sort of look at that and, ‘Oh, yes, that’s on today.’” (Both #P1).

One difference between wearable devices and other smart devices is that they are designed to be worn on the body almost constantly. This means that notifications are less likely to be missed, as they can be with smart devices: “So long as it's successfully connected, it will vibrate in my hand and so, honestly, that tiny little feature is actually probably the thing that's most interesting [in context, was taken to mean useful/important] about it” (#P3).
5.2.5. **Battery**

The battery topic is almost exclusively about battery life. Battery life is important as every wearable device requires power to function. This issue appears to be significant with respect to wearable technologies, as many require charging on a daily basis. This can have an impact on the wearable’s usage. This topic is referenced in 43 sources, including two interviews.

Battery life is a concern with many mobile devices. The data in this topic mostly relates to battery life, and the prevalence of this topic does show that it is an issue of significant concern to users. Users tend not to like having to charge their device every few days: “If it doesn't last a good few days – a week would be a good number to aim for – the user will start to have recharge fatigue as the device spends too much time off their face/wrist and too much time on charge” (#D31). One or two days appears to be average battery life for wrist-mounted wearable devices, which can annoy users: “It [smartwatch] does two days. I suppose that's not particularly good” (#P11).

5.3. **Concepts**

Due to the large number of topics, another level of abstraction from the data is required. To facilitate this, concepts were created. To allow this, nine concepts emerged from the research data. The concepts are (in order of prevalence): **Hardware Experience**, **Software Experience**, **IO** (Input and Output), **Personal, Wellbeing**, **Connectivity**, **Enterprise**, **Medical**, and **Industry**. These concepts are comprised of groupings of similar topics and provide further insights into the data collected. A fishbone diagram showing the major topics in each concept is shown below in Figure 5.
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Figure 5 - Concepts and Topics

5.3.1. Hardware Experience

The concept **Hardware Experience** was created to encompass all sections of the wearable that directly affect the experience that the user enjoys that are not programatically defined.
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This concept covers the form of the device and all other physical aspects that directly affect the user. Factors that indirectly affect the user are outside of the scope of this concept.

This concept is comprised of the topics: Fashion, Devices, Battery, Power, Geolocation, Comfort, NFC, App Interaction, RFID, Ambient Data, Memory and Beacons (in order of prevalence). The inclusion of three of the five most prevalent topics makes this concept the most prevalent, by a significant margin.

The topic Geolocation was considered for inclusion in Software Experience and IO but was placed in this topic as it is not software based and is not a simple input (as assisted geolocation uses a number of inputs and outputs). Geolocation is not in IO due to its compound nature, and is not in Software Experience due to the fact that it is combined to a singular input at a low level of the operating system, and is not by itself a feature of the software experience (i.e. it is used as an input to other parts of the software experience).

5.3.2. Software Experience

Contrary to Hardware Experience, Software Experience was created to encompass all topics that deal with the programatically-created (software-based) part of the experience presented to
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the user of the wearable. In other words, any part of the wearable experience that the user
interacts with but can’t touch (i.e. not a physical object).

This concept is comprised of (in order of prevalence) the following topics: Notifications, Context
Awareness, Social, UI (User Interface), Data, Interruptions, Paradigms, Privacy, User
Interaction, System Integration, Responsiveness, Peripheral Interaction, User Behaviour,
Usability, User Demographic, Problems, Security, User Experience, Design, Emotions, and
Dependence.

The large number of topics contributes to the prevalence of this concept, although many of the
topics are not very prevalent alone. The first 8 topics are the only ones that may be considered
highly prevalent.

5.3.3. **Input and Output**

![Figure 8 - Topics in IO](image)

**IO** (Input and Output), as a concept, exists to cover all input and output between the user and the
device. This concept is required because input and output can be hardware and/or software
based. Splitting input and output into **Hardware Experience** and **Software Experience** would
split the topics in a manner which could cause problems when trying to gain insights from the
data. Additionally, some input is collected subconsciously from the user (e.g. biofeedback), and
this is therefore not part of any other concept.
A large number of wearable devices are developed for personal, rather than professional use. This concept aims to cover all the topics related to personal use. Uses for wellbeing are not in this concept, as wellbeing fields of use are prolific enough to warrant their own concept.

The topics (uses) that make up this concept are as follows (in order of prevalence): Information, Navigation, Payment, Organisation, Transport, Home Automation, Entertainment, Time, Communication, Safety, Telephony, Lifestyle, Messaging, and Augmented Reality (Personal).
5.3.5. **Wellbeing**

This concept looks at how wearable devices may be used to encourage the wellbeing of their users. **Wellbeing** encompasses all health-related uses of a wearable outside a clinical context. The most prevalent topic in this concept is (unsurprisingly) *Activity Tracking*. The other topics are: *Sleep Monitoring, Exercise, and General Wellness*
5.3.6. **Connectivity**

![Figure 11 - Topics in Connectivity](image)

*Connectivity*, as a concept, covers communication between the wearable and other systems (in contrast to IO). This concept’s main topic is *Communication Systems*, followed by *Interoperability, Internet of Things*, and *Cloud* (i.e. cloud storage).
5.3.7. Enterprise

The concept **Enterprise** encompasses all white-collar uses of wearable technology, generally in an office-based environment. Due to the large number of business uses with limited references, the topic **Misc. Business** dominates this concept, accompanied by the topics **Marketing**, **Education**, **Security**, and **Management**.
5.3.8. **Medical**

![Figure 13 - Topics in Medical](image)

*Medical*, as a concept, covers health-related wearable use within a clinical context (in contrast to *Wellbeing*). The most common use appears to be *Monitoring*. The next most prevalent topic is *Diagnosis*, followed by *Treatment, Mental Health*, and *Administration*. 
5.3.9. **Industry**

The concept **Industry** is designed to encompass blue-collar usage of wearable devices (in contrast to **Enterprise**). Although not in common use, the most prevalent topic is **Augmented Reality (Business)**. The other topics mentioned (while not highly prevalent) are: **Machine Learning**, **Product Design**, **Safety (Industry)**, **Manufacturing**, and **Warehousing**.

5.3.10. **Summary**

Concepts were created as a further means of abstracting the data from topics. The nine concepts of **Hardware Experience**, **Software Experience**, **IO** (Input and Output), **Personal, Wellbeing, Connectivity**, **Enterprise**, **Medical**, and **Industry** emerged. These concepts were used to group topics according to common aspects.

**Software Experience** and **Hardware Experience** contained topics relating to the programmatic (software based) and the hardware-based, respectively, experience enjoyed by the user when using the wearable.

**IO** and **Connectivity** together encompassed all device communication. **IO** focused on communication between the device and the user, whereas **Connectivity** encompassed communication between the device and other systems.
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**Personal** encompassed personal uses for a wearable, such as organisation and receiving notifications.

**Wellbeing** and **Medical** focused on health-related uses for wearable devices. **Wellbeing** focused on uses outside a clinical context, and **Medical** focused on clinical uses.

**Enterprise** and **Industry** collated topics about business uses for wearable devices. **Enterprise** encompassed uses in white-collar jobs, whereas **Industry** focused on blue-collar uses.

### 5.4. Themes

![Figure 15 - Themes by Number of References](image)

This section discusses the three themes that have emerged in course of the research and investigates the relationships between and within themes. As shown in Figure 15, **User Experience** is the largest theme, both by references and sources. These themes are comprised of the topics and concepts that have emerged from the data, as described in sections 5.2 and 5.3 (respectively).

Themes are the highest level of abstraction from the data. From the coding of the data, Topics emerge (e.g. *Voice Input*). These Topics are grouped into Concepts (e.g. *Software Experience*) which then form Themes (e.g. *User Experience*). It should be noted that there are no Concepts under the theme *Perceived Value*. Its low number of Topics made Concepts unnecessary.
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The **User Experience** theme is the largest, and is comprised of four Concepts; **Software Experience**, **Hardware Experience**, **IO** (Input & Output) and **Connectivity**. To avoid it being confused with Perceived Value, it should be noted that User Experience covers what the user does and experiences, not why they do it or react to it. **Software Experience** covers anything programmatical on the device; Notifications are the most common topic. **Hardware Experience** covers the physical aspects of the device. Fashion and Battery are significant topics under this concept. **IO** encompasses all input and output from the user (direct or indirect); Biofeedback is the most significant topic. Finally, **Connectivity** focuses on communication between the wearable and other systems, with Connection Systems being the most prevalent topic in this concept.

The **Uses** theme is smaller than the **User Experience** theme but contains one more concept. The five concepts in this theme are: **Personal**, **Enterprise**, **Industry**, **Wellbeing** and **Medical**. **Personal** mostly, focuses on information and notifications provided by a wearable, in a personal use context. **Enterprise** focuses on wearable use in white-collar jobs, with marketing being a significant topic. In contrast, **Industry** focuses on blue-collar usage, where Augmented Reality is the main topic. **Wellbeing** focuses on health outside a clinical context, with Activity Tracking being the most prevalent topic by a significant amount. **Medical** focuses on the clinical side of health, with Monitoring (e.g. heart rate, breathing) being the most prevalent topic.

The final, and smallest, theme is **Perceived Value**. In contrast to **User Experience**, this deals with the reasons why people use wearable technology, not what they experience when using it. Due to the small number of topics, no concepts were used in this theme. There are eight topics: **Positive Motivators**, **Negative Motivators**, **Price**, **Abandonment Decision**, **Benefits**, **Expectations**, **Value** and **Usage**. **Positive Motivators** and **Negative Motivators** focus on why people start (or don’t start) using wearable devices, and **Abandonment Decision** focuses on why some users stop using them. **Price** covers the impact of the price of wearable devices on their perceived value (both positive and negative). **Expectations** focuses on what users expect from their wearable devices, and **Benefits** focuses on what the user actually receives. **Value** and **Usage** are very small topics that do not provide a large amount of information.
5.4.1. User Experience

Figure 16 - Coding Diagram with User Experience in Red
User Experience encompasses all aspects of the device that interact with the user and that impact the interaction (directly and indirectly). This section does not cover the use case of the device or the value of the device. This theme may be considered use-agnostic and value-agnostic, in a manner similar to usability theory.

User Experience is the most prevalent theme, with nearly twice the number of references of the next most prevalent theme, Uses (section 5.4.2).

The User Experience theme is comprised of four concepts. These concepts are, in order of prevalence: Software Experience, Hardware Experience, IO (Input and Output) and Connectivity. These concepts cover the four aspects of the User Experience.

Software Experience (section 5.4.1.1) is the interaction of the user with the software of the device, often via touch screen or an audio interface, and is created by programmers. Hardware Experience (section 5.4.1.2) is the interaction with the physical device, which covers issues like comfort and battery life issues. IO (section 5.4.1.3) covers direct input and output with the device. Biofeedback is a common form of input and output (e.g. Activity Tracking) as is screen input/output. Finally, Connectivity (section 5.4.1.4) covers the connection between the wearable and other devices. Wearable devices often connect via Bluetooth, but they have many other ways to connect to other devices (some wearable devices are even connected via cables).

5.4.1.1. Software Experience

Software Experience is defined as any programming/programmatical device that interacts with the user directly (e.g. apps, operating system, usability guidelines).

Software Experience, as a Concept, covers a wide variety of areas. The primary aspect of Software Experience seems to be the Notifications that wearable devices provide to the user, and users appear to approve of Interruptions (such as notifications) provided that the wearable demonstrates Context Awareness, providing the right information at the right time. Users also feel fairly strongly about the Social Impact of using their wearable, which is mentioned when different interaction Paradigms are with respect to the interface of wearable devices.

Unsurprisingly, Notifications is the largest topic in this concept. This is to be expected, as many smart devices mirror notification on a smartphone or a computer. The data shows that users appreciate the ability to see their notifications at a glance: “Do you like the idea of being able to
leave your phone in your pocket instead of constantly fishing it out?” (#D38). This topic is related to the Context Awareness topic, where the research suggests that users are open to receiving more notifications, if the device is aware of the context and sends appropriate notifications (e.g. informing the user when they need to leave to reach their next appointment in time, taking into account travel time): “It tells me where I am, I mean, it’s got the Google Maps, and it will tell me how long it’s going to take to get home” (#P3). Interruptions is another significant topic, where users mention that they don’t mind occasional interruptions, but persistent and/or common interruptions are found to be annoying. “Getting notified about Instagram likes will just drive you crazy” (#D34); “He had configured his smartwatch to only notify him if he got communications from his family, boss or other important people. Once in a while, he interacted with the device for a split second, and continued on with our conversation” (#D5).

The Social impact of devices also forms a significant topic in Software Experience, although it could be classed under Perceived Value (section 5.4.3). Although the form of a device does affect the social impact of a device, the research suggests that a lot of the impact is due to the software design. The unobtrusiveness/obtrusiveness of notifications plays a substantial part in determining social impact: “In the end, though, it’s a very handy feature, especially if your phone is in your bag – provided you’re alone or unconcerned with looking a little awkward talking to your wrist on a busy street” (#D12).

Interaction Paradigms are also mentioned, due to the fact that wearable devices require a different paradigm to other devices. This was mentioned mostly with respect to overall interfaces, rather than specific apps: “Trying to use the watch as a tiny touchscreen phone remains challenging, not-quite-intuitive, and error-prone” (#D24).

Other topics that were mentioned were Privacy (users were concerned, but it had no effect on usage), User Interactions (peripheral and quick interaction is valued), System Integration (slowly being developed, users value it), Responsiveness (lag in device response is hated), Ease of Use (generally not a problem).

Unexpectedly, Security was barely mentioned. Users appear to be concerned about the privacy of information collected by any organisation but are not concerned with unauthorised access to the data.
5.4.1.2. Hardware Experience

Hardware Experience is defined as any part of the direct interaction between the user and the device that is not programmatically defined (as opposed to Software Experience) and is not related to input or output.

The two most important issues to users appear to be the Fashion aspect of the wearable and the Battery life of the wearable (along with how it is charged). Users also appear to find Geolocation a useful feature but do take issue with the Comfort of their wearable.

Fashion is the most prevalent topic in this concept. This is due to the fashion aspect of the wearable having a significant impact on the way the user views the hardware. Most smartwatch users are interested in the overall look of the watch, and that it appears like a watch, rather than a gadget: "Watches serve a functional purpose, but they're also valuable accessories. Meet any occasion by dressing up, dressing down or going all out by swapping to a different band" (#D39).

The second most prevalent topic in this concept is Battery. Users are generally concerned about battery life. Users appear unhappy with the battery life (especially smartwatches) of many wearable devices. D24 makes note of this. A large number of wearable devices require charging every few days (or more often), which frustrates some users: "If it [the battery] doesn't last a good few days – a week would be a good number to aim for – the user will start to have recharge fatigue as the device spends too much time off their face/wrist and too much time on charge" (#D11); "Battery issues tend to plague those who wear it every day, since most smartwatches last for less than 24 hours before needing to be charged up again" (#D24). This is interesting, as mobile phones usually require daily charging, yet that does not appear to be a significant barrier to mobile phone usage.

The Power topic is similar to the Battery topic but discusses the methods of powering devices. Whilst most of the data refers to plug-in charging, users that have access to wireless charging appear to appreciate it: "Inductive charging is a breeze. I wish charging anything would be this easy" (#D34). A few references were made to the possibility of kinetic charging (charging by the movement of the device).

The aforementioned two topics are significantly more prevalent than the other topics, but the two topics Geolocation and Comfort are prevalent (in that order).
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The *Geolocation* topic could be considered in **Software Experience**, **Hardware Experience** or **IO**, but was classified in **Hardware Experience**. Primarily, this is due to the documentation referring to GPS as a hardware-oriented feature (along with items such as rotating bezels) rather than alongside software-orientated features. It was not placed under **IO** as it is a conglomerate of different inputs and data from the Internet (assisted GPS uses a number of sources to determine location). It was not placed under **Software Experience** because it is abstracted from apps at the operating system level. Generally, geolocation is used for navigation, although it has other uses (e.g. Pokémon Go). “I will cross-country ski, rather than downhill ski, so that means you can go into areas that aren’t manned, so there’s no lifts or anything like that, so it gives you the added benefit of being able to backtrack, on the path of which you came” (#P6).

**Comfort** data shows that there are two main issues affecting users. Often, users notice that wearable devices (especially wrist-mounted ones) are “bulky” and not as comfortable as a smaller device. Secondly, some users find wearable devices are just not as comfortable as their non-technological counterparts, for example some users find their smartwatches get sweatier than a traditional watch. “You need to be able to actually wear wearable devices, and anything that's uncomfortable is going to get abandoned quickly” (#D11).

Other Topics mentioned were **NFC** (Near Field Communication), **App Interaction**, **RFID**, **Ambient Data**, **Memory** and **Beacons** (Bluetooth broadcast devices). These were barely mentioned in interviews or documents, and do not provide a significant amount of information.

### 5.4.1.3. IO

**IO** (Input and Output) as a concept covers any input and output between the user and the wearable, conscious or unconscious. For example, a user tends to input data from a screen and receive output on it, but many devices measure heart rate and movement without conscious interaction from the user. The interface between the user and the wearable has various interaction styles which include the visibility usually with screens, biofeedback monitors, video, audio, voice input/control and other sensors.

As may be expected, the most prevalent topic in this area is **Biofeedback**. Many wearable devices measure heart rate (especially activity trackers). Biofeedback is not restricted to heart rate. Some skin-mounted wearable devices (e.g. smart bandages) measure sweat and blood pressure. “[The Canadian] Olympic team used smart costumes to track the team’s vital signs, which played a part in the team’s success at Sochi Olympics” (#D21).
Visibility is also a highly prevalent topic, but only two issues manifest from the data. Many wearable devices interact via a screen, and this screen is often exceptionally small. Users report having troubles interacting (both input and output) with these screens due to their small size (although some do mention that user interface design could improve this). Also, many screens are not easily read in bright light. “Keyboards need to be easily operable, large enough to be manipulated even with, in some instances, gloves on the hand. Displays should be legible in different types of environment and the display screen might need to be adjustable so it can be viewed from different angles and positions” (#D10). When wearable devices are used outdoors (e.g. smart watches), it is very difficult to glance at a wearable to discern what is on the screen. Under the Screen topic, users appear to be generally happy with the quality of the screens, but the Visibility topic shows the issues that arise.

Many users talk about methods of input (under the Input topic), and whilst most wearable devices appear to use touch screens, some devices use a “crown” which may be rotated for input and one smart jacket uses touch sensitive cuffs. Open/freeform input presents challenges: “Seeing text messages on your wrist is fine enough but responding on it is just silly. Aside from a few canned responses you can pre-program on your watch, it's just easier to whip out your phone to text back” (#D40).

Voice Control and Voice Input have their own topics. Most users mention using Siri for some tasks, such as setting timers and the like. Dictation appears to have both accuracy and social acceptance issues when in a public space, although in quiet conditions it appears to work well: “I like glazed donuts. I do not like glazed sidewalks’ came out as ‘I like late donuts I do not likely sidewalks.’” (#D41); “I expected people to be talking into their wrists (which looks stupid according to current societal standards), but there's no need for that. Still, I'm still not comfortable using dictation in public, Watch or no Watch, so not super helpful for me” (#D34).

Video and Audio are both methods of input and output (although audio input is covered in the previous two topics, and video is mostly covered in Screen). Whilst no interviewees mentioned either of these aspects, documents provided some insight into users’ experiences. Audio mostly mentioned the emergence of wireless earbuds, although other issues of audio were mentioned: “[In the Microsoft HoloLens] The sound is multidirectional, which is also pretty cool, I could hear holographic walls being broken as the game played” (#D42). Video mentioned the privacy issues associated with a camera in a wearable and touched on the idea of video calling on a wrist-mounted wearable: “Video calls and video recording for smart watches that activate their...
screen only when you look at them, similar to when you are looking at time or video streaming to your eye-wear” (#D3).

Non-conscious/subconscious input comes under the topic of Sensors. Biofeedback is a separate topic due to its prevalence (mentioned earlier in this section). The most common sensor mentioned (excluding biofeedback sensors) is accelerometers, which allow activity detection (e.g. step tracking, sleep monitoring). Other sensors are mentioned (e.g. barometer, gyroscope, humidity), but they are not very prevalent according to the data. Wearable devices allow sensing that is not possible with non-wearable devices: “The sensors are much better for measuring anything on your body than what a phone can do because it's attached” (#P3).

Clothing is a separate topic, as smart clothing can serve as a method of input and output. Most of the data about clothing covers using areas on clothes as inputs, although other possibilities exist. Whilst not a matter of input and output, kinetic charging via movement of clothing is discussed as a possible way to charge devices. Smart socks exist that may: “tell your iPhone which socks belong together, how often you've washed them, when they were produced, when you ordered them and when you need to buy some more” (#D44).

Unexpectedly, Glances were not mentioned much at all despite it being a principle of design for wearable devices. Whilst the topic is not very prevalent, all the sources report that glanceability is a very important part of making wearable devices usable.

Eyewear and Gestures were mentioned, but there is too little data in these topics to provide useful information.

5.4.1.4. Connectivity

Connectivity encompasses all interaction between a device and other devices/networks. Connectivity does not include any interaction with the user.

Wearable devices are generally mobile and can use a number of Connection Systems to connect with other systems. A number of wearable devices will only connect to their own proprietary systems unless they are connecting to Internet Of Things devices. Users appear to be unhappy with this, however, and value Interoperability between multiple types of systems.

The most prevalent topic in Connectivity is Connection Systems. Connection Systems mentions the technologies used by devices and issues that users have with connections. Overall, Bluetooth seems to be the most common method of wearable devices connecting to other systems.
Bluetooth 4.0 Low Energy makes this a power-efficient method of communication: “Yeah. I was actually worried at the beginning, thinking that having my phone with Bluetooth was going to actually be a problem. But being Bluetooth 4.0 it's low energy anyway” (#P13). Many wearable devices have the capability to connect to Wi-Fi and other systems, but these connections are more power intensive. The most common issue that users appear to have with connectivity is the fact that wearable devices sometimes disconnect for no apparent reason.

Interoperability is another prevalent topic in Connectivity. Many wearable devices are tied to one operating system. Activity trackers seem to be the only exception. In the smartwatch industry, the Apple Watch and Android Wear are the two most prevalent types of watches (with Samsung coming in third). Each of these only works with the same brand of smartphone, although Android Wear is developing interconnectivity with iPhones. The lack of interoperability appears to irk consumers, but not significantly. This may be due to the fact that consumers appear to be have a tendency to remain with one “ecosystem” for their technology: “The Apple Watch works with iPhones -- and only iPhones. Android phones work with Android Wear. Samsung's Gear S2 and S3 watches work with Android phones, too. Both Android Wear and Samsung watches pair with iPhones, but in a more limited way that is nowhere as good as what the Apple Watch offers. Fitness bands tend to work cross-platform, but not always” (#D45).

Interoperability is important for the Internet Of Things to operate effectively. Wearable devices seem to work well with the Internet of Things. This is not a very prevalent topic, as IoT (Internet of Things) devices are fairly new to consumers. Interestingly, wearable devices that do interconnect with IoT devices appear to be very interoperable, possibly due to the fact that most wearable devices manufacturers do not compete directly with IoT device manufacturers.

“Disappearing into the woodwork. All things talking to all things. Useful data. It may not be Apple, but the company or companies that will master these will usher in the new era of the Internet of Things where we finally get over our mainframe/PC/Wristop computer habit” (#D28)

Cloud interaction is only mentioned by one source, which is interesting as mobile devices (i.e. smartphones) make significant use of the cloud.
5.4.2. Uses

Figure 18 - Coding Diagram with Uses in Red

Figure 19 - Uses Concepts by Number of References
Uses is the second most prevalent theme. Uses, as the name suggests, covers all fields of use of wearable devices technologies. It is approximately half as prevalent (in number of references) as User Experience. There are many varied fields of use of wearable devices, and therefore the topics in this theme have been grouped into concepts. There are 5 Concepts in Uses: Personal, Wellbeing, Enterprise, Medical, and Industry.

Wearable devices have many uses in various aspects of our life, and the aforementioned Concepts intend to categorise the various uses into groups.

Personal (section 5.4.2.1) usage describes the uses that wearable have from a personal perspective, such as weather information, notifications from a smart phone and similar issues.

The Wellbeing (section 5.4.2.4) Concept covers everything impacting on the health of the user outside a clinical context, especially focused on activity tracking. The Medical (section 5.4.2.5) Concept, in contrast to Wellbeing (section 5.4.2.4), focuses on wearable uses in a clinical context.

The remaining two topics (Enterprise and Industry) have a similar relationship. Business (section 2.3.2) covers wearable uses in white-collar professions, whereas Industry (section 2.3.3) covers blue-collar professions.

5.4.2.1. Personal

The most prevalent concept is Personal. Personal use includes multi-purpose use of a wearable. Information is the most prevalent topic. There is a myriad of different types/pieces of information that users obtain via their wearable. The most common information collected appears to be weather information: “It also has the daily weather, so when I get up in the morning, I can see what I need to wear” (#P4). It should be noted that appointment and traffic information fall under a different topic (i.e. Organisation). Users also report that the ability to see information in the form of notifications on their wearable is useful; it allows them to decide whether the notification needs to be actioned without accessing their phone. For example, a user may receive a text on their watch during a meeting and quickly read it without pulling out their phone. They may then decide whether they need to reply immediately or whether it may wait until later.

Organisation includes alerts for upcoming appointments, to-do lists, reminders and other information regarding personal organisation. Appointment alerts are the most commonly
mentioned issue, which users appreciate. Users also appreciate the glanceability of the notifications (as noted in the Information topic): “The Calendar Glance is also clutch [useful/critical] for giving you a heads-up on any looming appointments and meetings” (#D12).

Navigation is another topic in this concept. It should be clarified that this is navigation in the physical world, not navigation of a software environment. A number of users (both mentioned in interviews and documents) find the ability to navigate (especially when walking) useful on a wearable. One document mentions that navigation was very useful in their experience with Google Glass (#D9). It is also suggested that a navigation system on a wearable could give you geographical information (e.g. informing you of a sale when you walk near one of your favourite clothing shops): “Current location on a pinch-zoomable mini-map. Walking directions. Automatic ‘where did I leave my car’ feature, based on the last time the phone connected to your car’s Bluetooth” (#D15).

Whilst payments on wearable devices is a relatively new feature, Payment featured as a prominent topic. Many users report that they would like/enjoy having the ability to pay on their wearable and have loyalty cards available on their wearable. “Wouldn't it be neat if you could pay for stuff just by tapping your wrist on a credit card terminal?” (#D46).

Home Automation, whilst uncommon, is a topic that a number of users are interested in. The majority of sources involve the wearable predicting the user’s needs (e.g. turning lights on when they enter a room) and the fact that wearable devices are usually with the user at home (more so than mobile phones). “Dimming lights or turn on an air conditioner when you arrive at home via smart light bulbs and the use of your wearable GPS tracking or wireless connection” (#D3).

Entertainment overlaps with Home Automation with respect to controlling music/video with a wearable. Simple wearable devices have been suggested for use at theme parks and resorts for identification/location of people: “Some theme parks and resorts are already looking to design a more seamless experience with radio frequency identification (RFID) in the form of a wearable, a technology that promises to streamline everything from reservations and tickets to keeping track of children” (#D47). Disney has already implemented a form of such technology. Also, some wearable devices can play media independently of other systems.

Time is a prevalent topic, as smartwatches are designed to tell the time, and can adjust times when needed with respect to the location of the user: “It adjusts the daylight savings automatically, so I no longer have to think about changing time on anything” (#P4).
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*Communications* covers both voice and text communication on a wearable. The most significant observation is that users like the ability to see who is calling on their watch, but do not like to take the call on the watch (using their phone instead). This observation is also true to SMSes and other text messaging services. Strangely, the idea of the watch having its own SIM card (allowing calls to be made and received purely on the watch) seems to not be an issue with users. “*Being able to see new messages as they come in without having to pull out a phone? Simple and useful.*” (#D18).

*Lifestyle* was a topic created for all personal uses that didn’t fit anywhere else. There are many unusual wearable devices in here, that only really show that some wearable devices are designed for unusual reasons: “*the watch can give you an exact verdict, by measuring how much time you spend with your loved ones.*” (#D51).

Finally, *Augmented Reality (Personal)* was mentioned only twice, although it is interesting that it was mentioned at all in respect to personal use for wearable devices. Both references refer to wearable devices under development, but many new wearable devices are being released and Augmented Reality is a growing field: “*I can see this [the Microsoft HoloLens] being huge for architecture, interior design, 3D modelling, and gaming.*” (#D4).

### 5.4.2.2. Enterprise

**Enterprise** is one part of wearable use in business (the other being **Industry**). **Enterprise** covers “white-collar” uses of wearable devices. Enterprise uses of wearable devices are uses that are focused on an office environment rather than a field environment. An example of such a use is a wrist-mounted wearable being used as a security access pass.

The most common enterprise use of wearable devices appears to be in **Marketing**. Wearable devices produce large amounts of data, which may be used to market specifically to the user. Many possible uses are presented, such as a user receiving personalised support and a wearable automatically checking-in a user at a store: “*In the case of a user entering a store and seeing a big screen with their name on it. Another possible integration would be for users who require support to interact with their device and a store employee will come to them.*” (#D3). In conjunction with other data, it could also automatically activate a loyalty program for the user.

Many other uses exist for wearable devices in business. A number of small topics (**Management**, **Marketing** and **Security**) mention this. A number of sources (user interviews and documents)
suggest that wearable devices can increase productivity in an enterprise environment. In a workplace it allows data about employees to be collected easily (although there are privacy issues associated with that) and allows rapid dissemination of information, along with small amounts of data entry. “And while there are some nefarious outcomes of implementing wearable watchmen in factories, in many workplaces employees say wearable devices can increase their productivity by as much as 8.5% as well as their wellbeing, rather than having an adverse effect” (#D30).

5.4.2.3. Industry

The Industry concept covers the “blue collar” uses of wearable devices in business. In contrast to Enterprise, the Industry concept focuses on wearable use outside an office environment. One example of such usage is an augmented reality system that may assist someone when repairing or maintaining machinery.

There is only one very prevalent topic in this section: Augmented Reality. Whilst nearly all of the data involved prototypes/speculation, it provides a large amount of insight as to what augmented reality could foreseeably do in an industrial context. Warehouse workers are specifically mentioned as possible beneficiaries of augmented reality systems: “Warehouse workers can optimize inventory management, quality control and site security with smart glasses such as those from Vuzix, which provide a real-time stream of data needed to monitor and improve processes on the factory floor” (#D23).

The other topics in this area: Machine Learning, Product Design, Manufacturing, Warehousing and Safety were not very prevalent. The main insight from these topics is that wearable devices can be used to allow users to access and input data quickly and in a mostly or entirely hands-free manner. The Safety topic also suggests that wearable devices could be useful in an emergency situation (e.g. smart watches broadcasting SOS signals, with augmented reality systems aiding emergency services).

5.4.2.4. Wellbeing

Wellbeing covers all health-related uses that are not directly medically related (i.e. not performed by clinicians). The measuring and monitoring of various activities, both normal and exercise orientated activities. The most prevalent example of a Wellbeing use of a wearable is tracking exercise, generally using a wrist mounted wearable, such as a Fitbit (Fitbit Inc., 2015).
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The four topics under this concept are: Activity Tracking, Sleep Monitoring, Exercise and General Wellbeing.

Activity Tracking is by far the most prominent topic, with nearly 10 times the references of the next most prevalent. The vast majority of users use their wearable for step tracking and for measuring running. A number of users also use GPS (when in a wearable) to measure distance when exercising: “Every time I complete a mile I get a gentle vibration to let me know. Glancing at my wrist while running is so much easier than turning my phone on, finding the app and checking the time/mileage” (#D13). Some wearable devices also alert users when they have been sitting down for over a specific amount of time: “The Apple Watch has the great feature that it will remind you to stand and walk around” (#D52). Other uses do exist, but they are not significant. Users tend to note that the ability to quantify their activity increases their general levels of activity. The Exercise topic bears out the same data (without adding any new insights).

The next most prevalent topic is Sleep Monitoring. Two main uses are borne out by the data. Firstly, sleep data is used for users to check the amount and quality of sleep they are getting. Secondly (although less common), users use apps on their wearable devices to wake them at the lightest point in their sleep cycle, allowing them to wake easier: “Wearing one at night could help track your sleep patterns and improve your sleep cycles, while also operating as an alarm clock for you by vibrating to wake you up” (#D53).

Finally, General Wellness is not a prevalent topic, although it does mention a wearable that measures UV exposure and warns the user when to seek shade.

5.4.2.5. Medical

The Medical concept covers health-related wearable devices used in a clinical context (i.e. all health-related usage not in Wellness). There are five topics in this concept. The most prevalent is Monitoring. Diagnosis and Treatment are of medium prevalence, and Mental Health and Administration have very little prevalence.

Monitoring is about day-to-day gathering of data that may be interpreted by health professionals (or by another system): “It will monitor your daily activities like the time you wake up, your working hours, the time you spend on exercise, your diet, etc. It will also be able to monitor your heartbeat, blood pressure and body temperature, electrocardiogram (ECG) to accurately determine your physical state” (#D54). The data shows that a large number of wearable devices
already collect health data, but privacy concerns appear to prevent the data from being shared with anyone. It is worthy of note that there is at least one system that does allow this. It is also suggested that some wearable devices could detect medical emergencies and alert emergency services (e.g. a device that checks heart rate detecting a heart attack).

*Diagnosis* is similar to monitoring, but this topic covers using wearable devices when the user is at a medical facility. Wireless telemetry is a common example of this. This topic appears to only mention a disparate number of wearable devices that can assist in diagnosing illness. All of them collect biofeedback, but that is to be expected: “Such devices not only promote safety and efficiency in hospitals, but also aid in managing patients’ medical records. For example, Proteus Discover uses a wearable patch to keep track of important medical information needed to determine the best course of treatment” (#D23)

*Treatment* provides more interesting data. A number of sources talk about patches to be worn on the skin that can detect symptoms and release medication into the body as needed: “Researchers in Korea have built a skin patch that’s thinner than a sheet of paper and can detect subtle tremors, release drugs stored inside nanoparticles on-demand, and record all of this activity for review later” (#D55). It was also suggested that wearable devices could be used to gather real-time information on how a patient is responding to any given treatment. In addition, smart wound dressings are under development that can monitor the status of a wound and act accordingly or alert the patient if something is wrong. This data in this topic shows that medical treatment with wearable devices is a mix of real-time detection and systems reacting accordingly.

*Mental Health* can be improved by the use of wearable devices, as they may be able to detect mental health episodes and help the user respond early: “For mental health concerns, the device goes the extra mile, connecting to a corresponding app with guided meditation exercises and data timelines that help users plan to proactively manage stress” (#D56). One such wearable alerts the user of an oncoming stress episode and talks the user through breathing and calming exercises. The data suggests that wearable devices are useful in detecting and preventing (where possible) mental health episodes.

*Administration* is the weakest topic, but it does give an interesting insight into how medical professionals could use wearable devices. The two suggestions given are that a wrist-mounted wearable could alert doctors when urgent information about a patient is available (rather than a
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nurse having to call/page them): "A doctor could wear one in the hospital and get notifications and alerts on it in an easy-to-use interface” (#D53), and that head-mounted wearable devices could allow surgeons to monitor the vital signs of a patient in an operation while still keeping their eyes on the patient. This topic’s data seems to suggest that medical staff can be assisted by wearable devices providing information in a more convenient and timely manner.

5.4.3. Perceived Value

![Figure 20 - Coding Diagram with Perceived Value in Red](image)
**Perceived Value (PV)** covers the value that the user believes that they gain from using (or intending to use) the wearable. This slightly differs from actual value, as users may perceive that they get certain benefits or limitations from a device, when the device has no actual effect. Perceived value (instead of actual value) is believed to affect the use of a device. For this reason, this theme is called perceived value. In this theme, only seven topics exist. For this reason, concepts were not used in this theme.

### 5.4.3.1. Price

The *Price* of any device can affect the perceived value in both a positive and negative manner. As this is the most prevalent topic in **Perceived Value**, it may be assumed to be the most significant. A user expects more from a $200 smart watch than they do from a $20 traditional watch.

Whilst this topic is very prevalent, there is only one issue that emerges from the data. This is that users tend to perceive wearable devices as expensive but generally worth it: "*I could see her already willing to justify the $289 price tag as she watched me scroll through screens displaying my heart rate and steps walked and stairs climbed*" (#D48). It can be a barrier to adoption, but it does not appear to impact user’s decisions to upgrade/replace wearable devices. It has also been
suggested that the high cost of wearable devices could impact the low enterprise use, as it requires significant capital expenditure.

5.4.3.2. Negative Motivators

The main reasons for not using a wearable (Negative Motivators) are twofold. The first reason is the style aspect. Wearable devices (especially smart watches) are seen as not stylish at this time: “She told me (in effect) that she thought she’d never be asked out while wearing an Apple Watch” (#D24). The second reason is the lack of a unique function. As many consumer wearable devices require connection to another device and mirror notifications, some prospective users don’t see the need for another device: “Wearable devices need to bring new stuff to the table. If they don't they're dead” (#D11).

5.4.3.3. Abandonment Decision

The inverse to adoption is abandonment. The topic Abandonment Decision covers the factors affecting abandonment. If users believe that the costs of using a wearable (e.g. charging regularly) are greater than the benefits, it is likely that they will abandon the wearable.

The level of abandonment varies with a survey of fitness wearable devices stating that, after an initial period of abandonment “71% returned to using their device again. Only 29% of initial abandoners, or 8% of the everyone, stopped using their fitness trackers for good” (#D37), whereas another survey reported that “more than half of the survey's respondents said that they no longer use their activity tracker, and a third of those stopped using the device within six months of receiving it.” (#D1).

The data suggests that there are a few reasons for abandonment. One of the more prevalent reasons seems to be general disillusionment. Once the enthusiasm of a new gadget wears off it appears that a number of users may lose interest. The data also showed, however, that the users did still tend to find wearable devices useful, just not as useful as they had originally believed.

Secondly, wearable devices that must be taken off regularly tend to become abandoned. If the device is uncomfortable or requires regular charging, users appear to be more inclined to abandon the device. The charging issue was unexpected, as smartphones require nightly charging as do many smartwatches. This does not appear to pose an issue for smartphone use, yet smartwatch users make note of it as an issue: “You have to charge it every night, and if you don't
charge it every night you won't be able to use it the next day, and it's a pain that I have to charge it” (#P9).

There are a few possible reasons for this. It is possible that the issue of regularly removing wearable devices (especially smartwatches) requires a paradigm shift. Another possibility is that the user sees the inconvenience of charging their smartphone as insignificant compared to the benefit they receive.

5.4.3.4. Positive Motivators

There are two main reasons users begin to use wearable devices (Positive Motivators). The first reason is to allow the user to quantify their activity (i.e. as an activity tracker): “The key thing I use it for is activity tracking. So, count steps and some things derived from that” (#P3). The second main positive motivator is the mirroring of notifications. A majority of wearable devices show notifications from another device (usually a smartphone), and this motivates users to start using a wearable: “Speaking of notifications, I'm finally not missing any. I would often not feel my iPhone vibrate from my pocket, so I couldn't rely on it to not miss things” (#D34).

5.4.3.5. Benefits

The Benefits of wearable usage is, surprisingly, not a very prevalent topic. The data suggests that the major benefit that users notice from wearable usage is the ability to peripherally interact with the wearable. Users tend to note the ability to quickly glance at their wearable and obtain information as a benefit over other devices: “I don’t want a watch that becomes a replacement for my phone. I want a companion. Something I can get quick notifications, simplicity, and tell the time. God I love this watch!” (#D49).

5.4.3.6. Expectations & Value

Expectations and Value both have very low prevalence (under 5 references each). Their data, when taken together, does provide two interesting insights.

Firstly, the data shows a belief that wearable devices must perform an important function faster (which is expected, but not always delivered) or perform an important new function to become integral to daily life: “The other problem with the current crop of smartwatches is the experience of using apps on wrist mounted devices does not always live up to the promise of getting stuff
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done faster or more efficiently. Just having to load an app on this type of supplementary device can feel like an imposition” (#D50).

Secondly, the data suggests that users would like workplaces to support wearable use, although few workplaces do “A recent study found that 70% of employees expect their workplace to permit the use of wearable technology while 46% think their company should fund the wearable technology” (#D25).

5.4.4. Summary

Themes are the highest level of abstraction from the data. This level allows for broad conclusions to be drawn about the data collected. There are three themes, User Experience, Uses and Perceived Value. The themes User Experience and Uses are composed of concepts. These concepts are comprised of topics. The third theme, Perceived Value, has a low number of topics within it, therefore concepts were not used, and Perceived Value is comprised only of topics.

User Experience is the largest theme, covering the entirety of experience enjoyed by the user when using a wearable. This theme is comprised of four concepts. The first concept is Software Experience, covering all programmatical (software-based) aspects of the user experience. Hardware Experience, in contrast, covers all hardware-based aspects of the user’s experience. IO (Input and Output) is comprised of all topics which deal with input and output between the user and the device. Finally, Connectivity is comprised of topics that cover communication between the device and other systems.

Uses, as a theme, focuses on the uses of wearable technologies. There are five concepts in this theme, relating to a context of use. Personal looks at general usage of a wearable in a non-professional context. Enterprise and Industry focus on uses in white-collar and blue-collar professions, respectively. Wellbeing and Medical cover the health aspects of wearable usage. Wellbeing covers uses outside a clinical context, whereas Medical covers use within a clinical context.

As previously mentioned, Perceived Value does not contain concepts, but is comprised of a number of topics. Positive Motivators, Negative Motivators and Abandonment Decision focus on the user deciding to use a wearable and their (possible) decision to stop using a wearable, respectively. Benefits and Expectations are linked topics, as Expectations are the benefits the user expects to receive from the wearable, whereas Benefits covers the actual benefits received.
This also affects the *Usage* topic, covering usage of the device. Finally, *Price* and *Value* are two topics that are important especially with respect to adoption. To adopt a wearable, the price must be acceptable, and the user must perceive value in the wearable.

### 5.5. Summary

The research data was drawn from interviews with users of wearable technology and by analysing documents where users mention and critique their experiences with wearable devices. The demographics of the users and documents analysed may be found in section 5.1.

The resulting data was coded, and the codes were grouped into a large number of topics, creating the first abstraction from the data.

From these topics, nine concepts emerged, and the topics were grouped into them. These concepts are: **Hardware Experience**, **Software Experience**, **IO** (Input and Output), **Personal**, **Wellbeing**, **Connectivity**, **Enterprise**, **Medical**, and **Industry**.

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**Figure 22 - Themes and Concepts**

The research data was drawn from interviews with users of wearable technology and by analysing documents where users mention and critique their experiences with wearable devices. The demographics of the users and documents analysed may be found in section 5.1.

The resulting data was coded, and the codes were grouped into a large number of topics, creating the first abstraction from the data.

From these topics, nine concepts emerged, and the topics were grouped into them. These concepts are: **Hardware Experience**, **Software Experience**, **IO** (Input and Output), **Personal**, **Wellbeing**, **Connectivity**, **Enterprise**, **Medical**, and **Industry**.
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At the highest level of abstraction from the data, three themes were created. These themes are: User Experience, Uses and Perceived Value. It must be noted that, due to the small number of topics in Perceived Value, concepts were not used in this theme. Instead, individual topics were used, not grouped by concept.

Figure 22 (above) shows a graphical representation of the themes and concepts. In the interests of clarity, only the upper two level of abstraction have been shows. Concepts have been depicted under the themes User Experience and Uses, whereas topics are shown under Perceived Value (due to its lack of concepts).

The insights provided by this data allows the construction of two models, covered in section 6.
6. Analysis and Theory Development

This section describes the models developed from the results enumerated in section 5. These models assist in the answering of the research questions posed in this thesis (section 4.1). These findings will be compared with the literature from section 2 during the enfolding in section 7.

In this section, the relationships between the three themes are discussed (section 6.1), providing the basis for a relational model explaining the usage of wearable technologies (section 6.2). This model uses relationships at multiple levels to explain which areas of the user experience have an effect on distinct sets of fields of use for wearable devices. A hierarchical model, explaining the motivations to use wearable devices is also explained (section 6.3). This model explains the motivations that affect the user’s decision to start using a wearable, and the motivations that encourage a user to continue using a wearable.

The strength of a relationship was based on a qualitative assessment that was influenced by the number of utterances, the strength of the utterances from the cases analysed, and the relevance between topics, concepts, and themes.

6.1. Relationships between themes

In this section, the relationships between the three themes (discussed in section 5.4) are examined. All the themes are interrelated, and therefore the relationships between themes, concepts and topics can provide useful insights. This section is intended to provide an overview of key relationships. Further insight into these relationships will be found in section 6.2, where the Usage Model is described.

6.1.1. User Experience - Uses

*User Experience* is the largest theme, and it has significant areas of overlap at the coding level. For this reason, the relationships between *User Experience* and other themes is investigated at the concept level.
The largest concept-theme overlap is between **Software Experience** and *Uses*. This is to be expected, as the uses of wearable devices are very dependent on the software. **Hardware Experience** and **I/O** also have significant overlap with *Uses*, unsurprisingly. **Connectivity** has almost no overlap with *Uses*. The same proportion of overlap occurs with respect to the theme **Perceived Value**, although the overlap is less (**Connectivity** has no overlap at all).
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At the topic level, the greatest overlap is the overlap of Biofeedback and Uses. This overlap suggests that biofeedback is quite a useful feature in wearable devices.

When investigating the relationship between topics in User Experience and concepts in Uses, the strongest relationship is that between Personal use and Notifications. The data shows that many users use their wearable devices to mirror notifications on other devices. Other strong relationships are between Biofeedback and Wellness, and Geolocation and Wellness. The Biofeedback relationship is unsurprising, due to the number of fitness and exercise related wearable devices, although the strength of the Geolocation relationship was unexpected. The data (both interviews and documents) suggests that geolocation is used when exercising to allow users to track their distance travelled when exercising and, one interviewee mentioned, to navigate the user back to their starting point. It should also be noted that Biofeedback has a significant relationship with Medical use (as is to be expected).

The strongest relationship with the Enterprise concept is privacy. Many users are worried about the privacy of their information in the hands of others. However, the relationship between Social impact and Enterprise use was unexpected. This data shows that this relationship exists due to a discussion on the social impact of enterprise wearable devices (i.e. does the wearable have to have a low social impact if it is mandated in the workplace). There is no consensus on this issue.

Interestingly, the strongest relationships with respect to the Internet of Things topic and System Integration topics were with Personal use. This is due to a number of devices/systems becoming available that can connect to wearable devices (usually via a smartphone). System Integration has a weaker relationship with Enterprise as wearable devices are not as commonly supported by organisations yet.

6.1.2. User Experience – Perceived Value

The User Experience Theme has a significantly weaker relationship with Perceived Value. There is no relationship at all with respect to Connectivity. The Hardware Experience relationship is weak, although it does mention that battery life does have an effect on value. It is surprising that this is not a stronger relationship. The relationship between IO and Perceived Value only contains 2 references and this perceived relationship may be coincidental (the data supports this).
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**Software Experience** has the strongest relationship with **Perceived Value**, and it is almost entirely based on the social aspects of the wearable. The data shows that a number of users have issues with the fact that a smartwatch can be seen as a gadget rather than a watch.

### 6.1.3. Uses – Perceived Value

**Uses** and **Perceived Value** have very few strong relationships. There are only two significant relationships that emerge from the data (and they are still not very strong).

The first relationship is between **Positive Motivators** and **Enterprise** (concept). The data suggests that businesses are adopting wearable technologies, at a rate that is expected to increase: “*However, the use of wearable devices in the enterprise is expected to grow 3x in the next two years*” (#D22).

The second significant relationship is between **Price** and **Activity Tracking**. The data shows that the relatively low price of fitness trackers (when compared to other wearable devices) seems to be encouraging consumers to purchase them.

Oddly, there appears to be no relationship at all between **Perceived Value** and **Medical**, or between **Value** and **Uses**. There is no reason immediately apparent for this lack of relationships.

### 6.2. Usage Model

The model of the uses of wearable technologies is described in this section. This model provides an understanding of how wearable devices are currently used, and which aspects of the user experience significantly impact on different fields of use. This section is based on the relationships between the **Uses** and **User Experience** themes and their Concepts and Topics, with a few relationships with topics in **Perceived Value**. A number of these relationships were mentioned in section 6.1.

This section discusses the relationships between Themes (section 6.2.1), then progresses to relationships at the Concept level (section 6.2.2). Concept-Topic relations are discussed with respect to **Perceived Value**, as **Perceived Value** does not contain concepts (section 6.2.3), followed by relationships between topics (section 6.2.4). An overview of the model may be found in section 6.2.5.
6.2.1. Thematic relationships

The Uses theme has a significant relationship with User Experience, but not with Perceived Value. This implies that the User Experience impacts strongly on the uses of wearable devices, rather than the perceived value. This is surprising, as Positive Motivators, Negative Motivators and Abandonment Decision are significant topics in Perceived Value.

6.2.2. Conceptual relationships

![Figure 25 - Concept Relationships in the Usage Model](image)

The relationship between Software Experience and Uses is relevant. The data demonstrates that a good software experience is important in wearable usage.

The relationship with Software Experience focuses on the Personal and Enterprise concepts. The data suggests that a common belief is that wearable devices will become more contextually aware in the future. Another common thread is that wearable devices allow data/notifications to be accessed in an unobtrusive manner. Enterprise also focuses on how wearable devices could
integrate with other systems. The low social impact of this appears to be valued in both personal and enterprise concepts.

**Enterprise** has no other strong relationships, but **Personal** has medium strength relationships with both **Hardware Experience** and **IO**. The data supporting the relationship with **IO** shows that users like geolocation but do take issue with screen readability and size. The **Hardware Experience** data is varied, but generally discusses using NFC and RFID technologies for uses such as payment.

**Wellbeing** has a less prevalent relationship with **Software Experience**, and the information shows that this relationship is mostly about accessing fitness data. **Wellbeing** has a strong relationship with **Hardware Experience** and a medium strength relationship with **IO**. The **Hardware Experience** relationship show that geolocation is valued as a feature when wearable devices are used for wellbeing purposes, and the **IO** relationship shows that biofeedback (e.g. heart rate monitoring) is both common and appreciated when a wearable is used for wellbeing.

The relationship between **Software Experience** and the **Medical** and **Industry** concepts is very weak, partly due to a lack of data. These two concepts do not have any strong relationships or a great deal of data, suggesting that they are not areas where wearable devices are commonly used at this time.

The **Medical** concept has its strongest relationship with the **IO** concept. The data suggests that medical wearable devices are mostly used for monitoring patient data. This concept has no strong relationships with other concepts.

**Industry** has a medium strength relationship with the **IO** concept, mostly about the possibilities of augmented reality in the future.

It is worthy of note that only **Personal** and **Wellbeing** have any relationship with **Connectivity**, and these relationships are very weak. It may be assumed that connectivity of wearable devices is not an important factor in wearable usage. This may, inversely, show that connectivity of wearable devices is an expected feature, but the method of connection is not important, in the same manner that mobile phone users are usually not concerned about how they are connected to the mobile network.
6.2.3. **Concept – Topic relationships (Perceived Value)**

The theme *Perceived Value* does not have concepts, due to the small number of topics. To create this model, concepts from *Uses* are compared directly with topics from *Perceived Value*.

There are no strong relationships between *Uses* and *Perceived Value* (PV), but some relationships do exist.

The strongest relationships are between *Enterprise* and *Positive Motivators*, and *Wellbeing* and *Abandonment Decision*. A further relationship exists between *Wellbeing* and *Price*, but its data shows it to be irrelevant. The former discusses possible opportunities for enterprise users to adopt wearable devices but, as it is speculative, it is not relevant to this model. The relationship between *Wellbeing* and *Abandonment Decision* is, however, relevant. People tend to abandon fitness trackers (a very common wearable) either due to disappointment that it did not help them achieve their health goals (e.g. weight loss) or they get frustrated with the reminders/inability to meet the goals set by the wearable.

There are no other relationships in this area that provide meaningful information relative to this model.
6.2.4. **Topical Relationships**

At the topic level, there are a vast array of very weak relationships, which have been discarded as outliers. There are also some strong relationships, that do provide insight into wearable usage.

*Activity Tracking* has a significant relationship with *Geolocation* and *Biofeedback*, and the data reinforces the conclusions made from the *Hardware Experience/Wellbeing* relationship mentioned in 6.2.2.

Unexpectedly, *Activity Tracking* also has a significant relationship with *Fashion*. The data shows that activity trackers are not used when unfashionable, regardless of their utility function. It also posits that activity trackers can be fashion statements.

*Notifications* and *Organisation*, as well as *Notifications* and *Information* have significant relationships. The data shows that notifications to remind users of events/meeting/etc… or to present information when it is believed to be needed are seen as useful, despite the interruption factor.
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The strength of the Notifications/Organisation relationship is only matched by the strength of the relationship between Misc. Business and Privacy. The data in this relationship shows a fear of data being collected and used without the interests of the user of the wearable (and maybe without their knowledge). It does not, however, suggest that it has an effect on wearable usage.

Medical monitoring (Monitoring) has a significant relationship with Biofeedback, as is to be expected, and the data showed that medical monitoring devices (naturally) take biofeedback as part of their core functions. No other insights were found in inter-topic relationships.

6.2.5. Overview

The Usage model is based on the relationships between the Uses theme and the other two themes to determine which factors affect usage and which uses are affected by these factors. This model provides an answer to the research question posed in section 4.1.2.2: “How are wearable devices currently used?”.

Software Experience (concept) has a significant effect on usage when used in Personal and Enterprise environments (both concepts). Wellbeing (concept) is also affected to a lesser extent. These are primarily due to the low social impact many wearable devices have with respect to data access and notifications.

Hardware Experience (concept) has a significant effect on Personal and Wellbeing use. Both uses are affected by geolocation and Personal use is also affected by NFC and RFID functionality.

IO affects all uses (except Enterprise), and it strongly affects Medical and Wellbeing uses. This is because medical monitoring devices use biofeedback, as do activity trackers. Personal uses are also significantly affected by screen size and readability (e.g. reading in direct sunlight) issues. The lack of a significant relationship between IO and Enterprise must be noted (as all wearables use input and output to some extent), although the meaning of this is unclear.

Another important relationship is between Activity Tracking (topic under Wellbeing), and Abandonment Decision (topic under Perceived Value). This impact is due to disillusionment when users purchase activity trackers and generally do not receive the benefits that they expected relative to the costs of using the device (e.g. regular recharging).
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At the topic level, there are two significant relationships. Notifications has a significant relationship with Organisation and Information. Users appreciate notifications when they are useful, regardless of the interruption.

An online (survey-based) study suggested that perceived attributes strongly affect adoption of smartwatches, primarily relative advantage (Hsiao, 2017). Smart glasses have also been the subject of uptake studies (Basoglu et al.)

### 6.3. Motivation Model

The model described in this section investigates the motivations of users of wearable technologies. This section answers the question “Why do users use wearable devices?” posed in section 4.1.2.3. This model uses the theme *Perceived Value* as a basis for its hierarchical form.

This section contains two sections, Pre-Usage (section 6.3.1), which discusses the motivations that encourage users to start using wearable devices, and During Usage (section 6.3.2), where the motivations to continue using wearable devices is discussed.

The data collected did not provide a large amount of information about the motivations to use wearable technologies, although it is assumed that the most prevalent motivations have been discovered. The limitation of the data is caused due to the primary focus of the research being on the uses and user experience of wearable technologies. The motivations behind the use of wearable technologies were not a focus, therefore the data upon which this model is based was not collected in a focused manner.
Figure 27 - Motivational Model

Figure 27 shows how the motivation model has been split into two ad-hoc concepts. This is due to evidence showing that people’s motivations to purchase wearable technologies differ from their motivations to continue to use it (or not). A lack of significant relationships between the two concepts underscores this distinction.
6.3.1. Pre-Usage

Pre-usage Factors are the factors that motivate the user to purchase/use a wearable. The three topics of this concept are Negative Motivators, Positive Motivators, Expectations and Price.

Negative Motivators is the largest topic in this concept, and it covers a variety of reasons why people decide to not use wearable devices, while Positive Motivators encompasses reasons why people decide to use wearable devices. Expectations and Price are separate topics, as they are both prevalent and can either encourage or discourage the decision to use a wearable.

The main reasons for not using a wearable (Negative Motivators) are twofold. The first reason is the style factor. Wearable devices (especially smart watches) are seen as not stylish at this time: “She told me (in effect) that she thought she’d never be asked out while wearing an Apple Watch” (#D24). The second reason is the lack of a unique function. As many consumer wearable devices require connection to another device and mirror notifications, some prospective users don’t see the need for another device: “Wearable devices need to bring new stuff to the table. If they don’t, they’re dead” (#D11).

There are also two main reasons users begin to use wearable devices (Positive Motivators). The first reason is to allow the user to quantify their activity (i.e. as an activity tracker): “The key thing I use it for is activity tracking. So count steps and some things derived from that” (#P3).
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The second main positive motivator is the mirroring of notifications. A majority of wearable devices show notifications from another device (usually a smartphone), and this motivates users to start using a wearable: “Speaking of notifications, I'm finally not missing any. I would often not feel my iPhone vibrate from my pocket, so I couldn't rely on it to not miss things” (#D34).

Expectations also affect motivation to use a wearable. Users place certain expectations on a wearable, which may influence their decision to use it. It is worthy of note that these expectations may not be met, but by such time the user has already started using the wearable. The utility value of the wearable appears to affect the expectations: “wearable devices need to fulfil some kind of utility that is integral to our daily lives” (#D57).

Price is also an issue with deciding to use a wearable. The high price of wearable devices appears to make businesses struggle to justify the expense of deploying wearable devices to their staff, even though the benefits are apparent: “As watches with GPS come down in price, I could imagine things like couriers or delivery trucks and so on actually having them. And that way head office knows exactly where they are as they're routing” (#P3). People also find justifying the cost of wearable devices difficult, although the increasing number of features in wearable devices helps justify the price: “She added that while early editions of fitness trackers and smartwatches came with a hefty price tag that ‘consumers couldn't justify’ for checking steps, calories or notifications, there is today a plethora of wearable makers that have entered the market with cheaper alternatives with either niche or increased functionalities for consumers” (#D58).

Smartwatches are generally priced competitively with other high quality watches, but high quality watches are generally worn for many years, whereas smartwatches are perceived to become obsolete quickly: “It’s priced fairly high, so if you’re investing like $900 or $800 on a watch, the idea is that it should be timeless and should last for a while, but it kind of contradicts the thing itself, because an electronic device has a maximum longevity of three years” (#P2).

In summary, there are a number of pre-usage factors affecting the motivation to purchase and use a wearable. The price point is significant for both business and personal use, as wearable devices are generally expensive. The wearable must not be unfashionable and must appear to provide a utility value that is integral to the daily life of the user. Finally, notifications and activity tracking are also expected of many wearable devices and are significant factors when the user decides to adopt a wearable.
6.3.2. **During Usage**

Once a user has adopted a wearable, different factors affect their motivation to use it and to continue using it. *Abandonment Decision* is a very significant issue, as it occurs when the user is no longer motivated to use the wearable. The benefits of the wearable are also significant, as is the value provided.

Abandonment is the largest topic in this section, comprising more than half of the document and interviews analysed. Many users abandoned their wearable soon after purchasing it. Wearable users tend to return to using their wearable devices (in the case of activity trackers) after some time. The main issues that influence abandonment are battery life and comfort. Abandonment occurs during usage and can occur multiple times for the same wearable device.

“More than half of the survey's respondents said that they no longer use their activity tracker, and a third of those stopped using the device within six months of receiving it” (#D1)

“71% returned to using their device again. Only 29% of initial abandoners, or 8% of the everyone, stopped using their fitness trackers for good” (#D37).

“The more users have to take the wearable off, the more likely it is that the wearable stays off “(#D37)
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“You need to be able to actually wear wearable devices, and anything that's uncomfortable is going to get abandoned quickly” (#D37)

The Benefits topic differs from the Expectations topic (Pre-Usage) due to the fact that Benefits covers actual benefits, whereas Expectations covers perceived benefits in the future. Subtle notifications appear to be a significant benefit experienced by users: “There's countless examples where we only access our iPhones for one to two seconds. The Apple Watch alleviates that! In a really subtle, non-distracting way” (#D38). Unfortunately, apps for business are scarce, limiting the benefits experienced by organisations that employ wearable devices: “The absence of intelligent apps is a double-edged sword as the cost for building out the systems needed to support devices is high” (#D25). Usage does mention that usage of wearable devices can increase productivity when used well: “In many workplaces employees say wearable devices can increase their productivity by as much as 8.5% as well as their wellbeing, rather than having an adverse effect” (#D30).

Value covers how the wearable provides value to the user on a daily basis. The more value the wearable provides, the more likely the user is to be motivated to use and continue to use it: “The Disney MagicBand which offers real value to wearers by allowing them to enter park rides, make purchases and unlock their hotel rooms all through a wave of their hand. It even has the potential to keep visitors' kids more safe [sic], by quickly locating a lost kid through an added GPS tracker” (#D20). If the wearable does not provide value, there is little motivation for the user to continue using it.

In summary, abandonment is a significant issue with respect to wearable use, usually due to a mix of poor battery life and lack of comfort. Users are often motivated to continue to use their wearable by certain value that the wearable provides to the user day-to-day. The most significant benefit enjoyed by users is the ability to receive information in an unobtrusive manner. Businesses may also enjoy benefits of increased productivity and employee happiness, but the lack of business apps may cause issues.

6.3.3. Overview

This model attempts to explain why users adopt and use wearable technology, providing an answer to the secondary research question: “Why do users use wearable devices?”, posed in section 4.1.2.3 To do so, the Perceived Value theme was split into two areas, Pre-Usage and During Usage. A hierarchical model was chosen due to the lack of significant relationships
between *Perceived Value* and the other themes, and the topics within *Perceived Value* with each other.

Analysis of the Pre-Usage topics show that price, fashion and perceived usefulness are the main aspects that affect uptake of wearable devices, followed by the ability to track activity and receive notifications (usually from a phone).

Once the user has adopted a wearable, other issues make the user continue to use the wearable (or not). The unobtrusiveness of notifications appears to be the main benefit enjoyed by the user. Poor battery life and uncomfortableness are problems regularly experienced that can lead to abandonment.

### 6.4. Summary

In this section, the relationships between themes are examined and two models are described. The relationships between themes, concepts and topics are examined (section 6.1), which provide the basis for the Usage Model (section 6.2), showing how different aspects of the User Experience affect different fields of use for wearable devices. A hierarchical model, the Motivation Model (section 6.3) is also explained, enumerating the factors that cause users to begin to, and continue to use, wearable devices.
7. Enfolding Literature

7.1. Introduction

In this section, the findings (section 5) and the analysis of the findings (section 6) are enfolded with the literature reviewed in section 2. This is in accordance with the methodology covered in section 3.

Two models and a taxonomy are enfolded in this section. Firstly, the models developed in sections 6.2 and 6.3 are compared with the literature covered in section 2. This section enfolds the literature with respect to the usage model (section 7.3) and the motivation model (section 7.4).

The usage model is divided into two parts. The first part examines the relationships at the theme-concept level with Software Experience (section 7.3.1), Hardware Experience (section 7.3.2), and Input and Output (section 7.3.3). The enfolding is finalised with enfolding topical relationships (section 7.3.4). This usage model advances current usage theories (Ernst et al., 2016, Nelson et al., 2016) by showing how non-wearable usage theories may apply to wearables, and discovering which specific studies on wearable usage are generalisable.

The motivation model is divided into two sections, Pre Usage (section 7.4.1) which describes the motivations to begin using a wearable and During Usage (section 7.4.2) which explains the motivations that keep users using a wearable. Similar to the usage model, the motivational model builds on current models of technology uptake and continued usage (Venkatesh et al., 2003, Venkatesh et al., 2012, Adapa, 2016, Basoglu et al., 2017, Brandao and Regina, 2016, Cho and Park, 2016, Hsiao, 2017, Kim and Shin, 2015, Rauschnabel et al., 2018, Rauschnabel et al., 2016), and shows the differences with respect to wearable uptake and continued usage.

The taxonomy covered in section 3 is enfolded in section 7.5. As this taxonomy was generated from peer-reviewed literature, it is enfolded with the findings, and a number of examples are given to show that the taxonomy is in accord with the findings. At the time of writing, no taxonomy for the classification of wearables existed, so this does not build on current knowledge of taxonomies, although it is based on the analysis of literature about wearables.
7.2. Concepts

Nine concepts emerged from the topics, as discussed in section 5.3. This section enfolds and validates eight of these concepts, by comparing them with relevant literature found in the literature review (section 2). The concept Connectivity is not enfolded, as it is not used in the usage or motivational model. This concept is not related to the Connectivity attribute in the taxonomy.

7.2.1. Software Experience

Software Experience is defined as all topics that deal with the programmatically-created (software-based) part of the experience presented to the user of the wearable. This is also sometimes referred to as the user interface, although a broad definition of user interface could include the hardware experience.

One of the most well-known pieces of literature about this is by Nielsen, where ten heuristics for a user interface are explained (Nielsen, 1995). Some research has been done on wearable user interfaces and efforts have been made to develop guidelines (Yoon et al., 2017, Löfblom, 2017). It is also worthy of note that a number of wearable manufacturers publish guidelines about the software experience of their own wearable devices (Google Inc., 2015a, Microsoft Inc., 2015a, Apple Inc., 2015b).

The literature tends to look at the Usability, Ease of Use and UI (User Interface) of the wearable (all topics). No literature was found specific to other topics in this concept. All topics in this concept are discussed in section 5.3.2.

7.2.2. Hardware Experience

The concept Hardware Experience encompasses all sections of the wearable that directly affect the experience that the user enjoys that are not programmatically defined (software-based). This includes the form factor of the device, the comfort of the device, and the battery life of the device amongst other issues.

Most studies into the hardware experience of wearable devices focus on specific wearable devices or classes of wearable devices (Marin et al., 2017, Fortmann et al., 2015, Liu et al., 2016, Zucco and Thomas, 2016). Some, however, do generalise with respect to the “wearability” of
wearable devices (Gemperle et al., 1998). Due to the fact that hardware experience is generally studied as a whole, research with respect to specific topics could not be found.

7.2.3. Input and Output

IO (Input and Output), as its name suggests, covers all input and output between the user and the device. In this concept, non-conventional methods of input and output are included (i.e. methods that aren’t touch screen etc…). Non-conventional methods in the literature are mentioned in section 2.2.6.

Input and output has been studied extensively in the field of wearable devices, due to the different interaction paradigm required. One example of a non-conventional system is a smartwatch prototyped that has four extra methods of expressing input (Xiao et al., 2014), which relates to the Input topic. Another system changes shape to assist navigation by the user (Spiers et al., 2015). This is validated as a concept by a large number of studies which investigate different ways of receiving input from the user and expressing output to the user (Han et al., 2017, Kim et al., 2016c, Kucukyildiz et al., 2017, Mohammed et al., 2016, Paudyal et al., 2017, Surale, 2015, Vega et al., 2015, Vega and Fuks, 2013, Yoon et al., 2016). In this concept, it is difficult to match individual topics to research.

7.2.4. Wellbeing

In this research, Wellbeing encompasses all health-related uses of a wearable outside a clinical context. This means wearable devices used for activities like fitness tracking and other such purposes, but not wireless telemetry systems in a hospital etc….

There is a multitude of scholarly papers about wearable devices being used for Activity Tracking and tracking Exercise (Angulo et al., 2016, Becker et al., 2017, Goodyear et al., 2017, James, Kumari et al., 2017, McCallum et al., Prasopoulou, 2017, Hwang et al., 2016b). Smart clothes may be used for wellbeing to gather biofeedback, which may then be analysed (Chen et al., 2016, Trindade et al., 2016, Yin, 2017), assisting to validate the General Wellness topic. Both of these fields of use are reflected in the research. Very little research was found with respect to Sleep Monitoring.
7.2.5. Medical

Medical uses may be considered to be the inverse of Wellbeing uses. Medical focuses on wearable use for health within a clinical context (e.g. in a hospital). The most common uses appear to be Monitoring of patients and Diagnosis of illnesses. Most wearable devices that exist are designed to facilitate both uses.

There are a number of wearable devices that deal with monitoring of patients (Emaminejad et al., 2017, McWhorter et al., 2017, Polanco et al., 2017, Webster et al., 2017).

A number of medical wearable devices are not specific to one condition, and the data they provide allow diagnosis of illness (Li et al., 2017a, Enewoldsen, 2016, Gaskin et al., 2017, Szczsna et al., 2017, Trindade et al., 2016, Zheng et al., 2016). One study suggests how this data could be mined to allow detection of medical conditions earlier (Zhang et al., 2017). Mental Health and Medical Administration were mentioned in a few studies, but not to any extent.

7.2.6. Personal

Many wearable devices are designed for use in the daily personal life of the user. This concept deals with such uses. In other words, any uses that are not professional or related to the health of the user are covered in this concept.

There are a myriad of personal uses for wearable devices. Navigation is a common use and a number of wearable devices have been proposed for this (Spiers et al., 2015, Funk et al., 2014, Rudi et al., 2016).

A variety of consumer wearable devices exist, and are generally purchased for personal use (i.e. not issued by an organisation) (Google Inc., 2016b, Apple Inc., 2015a, Google Inc., 2016a, LG Australia, 2016).

As the personal uses are varied with respect to wearable devices and many wearable devices are multi-purpose, research focused on specific topics in this concept was not found.

7.2.7. Industry

The Industry concept encompasses wearable usage in “blue-collar” jobs. The largest topic in this concept is augmented reality, especially in situations such as warehouse picking.
A number of studies discuss the use of Augmented Reality (and other wearable devices) in warehouse picking contexts, which supports a section of the usage model (McFarlane et al., 2017, Muguira et al., 2009, Weaver et al., 2010, Iben et al., 2009, Funk et al., 2017).

In addition, Safety is a topic in this concept, and studies that prototype safety wearable devices for the workplace support these findings (Teizer, 2015, Kim et al., 2016c, Kritzler et al., 2015, Le et al., 2015).

The other topics in this concept did not have any peer-reviewed research validating them. All the topics in this concept are discussed in section 5.3.9.

### 7.2.8. Enterprise

**Enterprise**, as a concept, covers usage of wearable devices in “white-collar” jobs. The uses of business wearable devices are varied among a large number of fields of use.

The research also shows an amount of research into enterprise wearable devices, but the research is also specific and disparate. The only example of two studies in the same area relate to conference visitors, and even then the fields of use differ significantly (Kanis et al., 2005, Paradiso et al., 2010).

A number of other wearable devices exist for other specific cases (Radevski et al., 2015, Madan et al., 2004, Rijnsburger and Kratz, 2016). The topic Misc. Business may be considered to be validated by these studies. The other topics in this concept did not have peer-reviewed literature to support them. All the topics in this concept are discussed in section 5.3.7.
7.3. Usage Model

Figure 30 - Conceptual Relationships in the Usage Model
The usage model has discovered a number of significant relationships between the user experience and fields of use of wearable devices that affect the fields of use of a wearable. These relationships are explained in depth in section 6.2. In summary, they are as follows:

- **Software Experience** impacts on **Personal** and **Enterprise** significantly.
- **Hardware Experience** impacts on **Personal** and **Wellbeing** use significantly.
- **IO** impacts on **Medical**, **Wellbeing**, **Personal** and **Industry** uses
- **Activity Tracking** has a significant impact on **Abandonment Decision**, due to disillusionment when tracking activity does not necessarily lead to increased health benefits
- **Notifications** impacts on **Organisation** and **Information**, showing that users appreciate relevant notifications
7.3.1. **Software Experience Relationships**

There are two relationships between **Software Experience** and **Uses**. The relationship with **Personal** use is based mostly on three factors. Firstly, the context-aware nature of wearable devices. Secondly, the unobtrusiveness of notifications when viewed on a wearable. Finally, the social impact of a wearable. The **Enterprise** use relationship shares these factors, but also shows system integration with other systems as a factor with respect to usage.

Context-awareness involves the wearable knowing the context that it is in and responding accordingly. The usage model suggests that context awareness impacts on personal use. One study concludes that context-awareness is important in the user experience and provides practical benefits to the user (Häkkilä and Mäntyjärvi, 2006). This study also suggests that notifications should be filtered to ensure that they only give the user information relevant to them at the time.

In general, the model states that the ability to read notifications at a glance, without requiring them to access another device affects use. Whilst not peer reviewed, two sets of corporate usability guidelines support this. The first principle for Samsung Gear wearable devices says that information should be “glanceable” (Samsung, 2014a, Samsung, 2014b). In addition, two principles of Android Wear guidelines state that interactions should be no more than five seconds and to “design for the corner of the eye” (Google Inc., 2015a).

The unobtrusiveness of notifications and context-awareness may be considered to be specific aspects that affect the social impact of a wearable, whilst it should be noted that the model does mention social impact separately. A large number of studies into wearable devices look at the social impact. A study of the social impact of notifications suggests that the impact on others may be less than the user perceives (Fruehauf and Al-Khalifa, 2016). Social impact may be minimised by “hiding” the technology (Vega and Fuks, 2013, Vega et al., 2015, Vujic et al., 2016, Saadatzi et al.). The importance of social impact in enterprise use is mentioned in a study that attempts to minimise it by incorporating technology into a suit (Toney et al., 2002).

Integration of wearable devices with other systems is mentioned in the model with respect to **Enterprise** use. Whilst there are few studies with respect to integration of wearable devices, some literature does mention current enterprise use of mobile technology integrated with other systems (Gastaldi, 2014). Another study suggests that wearable devices allow “smart environments” to be created (Topić and Russo, 2016).
7.3.2. **Hardware Experience Relationships**

The concept **Hardware Experience** has a relationship with both the **Personal** and **Wellbeing** concepts in the usage model. The relationship with **Personal** is centred around using short-range communication (e.g. NFC and RFID) and the relationship with **Wellbeing** is based on geolocation in activity tracking.

**Hardware Experience** has a significant relationship with **Personal** uses. The relationship is based on short-range communication, and there are two major methods of communication, Near Field Communication (NFC) and Radio Frequency IDentification (RFID).

NFC is commonly used for payments, as the model states, but not uniquely. The number of NFC cards, also known as “smart cards”, are mentioned in a paper suggesting a NFC “wallet” to hold all cards in one wearable device (Al-Chalabi et al., 2015). Google Pay is an example of one NFC wallet system currently in use and available for wearable devices as well as other devices (Google Inc., 2018a).

RFID is a similar technology, used generally for identification purposes. A number of papers mention RFID as a method of communication between a wearable and another device (Chen et al., 2011, Manzari et al., 2011). One analysis of patent data suggested that China had approximately 3 billion RFID tags in 2009 (Trappey et al., 2011). RFID tags are also used in some “smart home” systems (Noury et al., 2011).

The **Hardware Experience** relationship with **Wellbeing** centres specifically on **Geolocation** in the context of activity tracking.

A number of papers make reference to the fact that a number of activity tracking wearable devices have GPS capability (Becker et al., 2017, Angulo et al., 2016). One interesting wearable prototyped used GPS location to track skateboard tricks (Dastan, 2016). A number of exercise-based games require GPS capability in a wearable (Goodyear et al., 2017).

7.3.3. **IO Relationships**

**IO** (Input and Output) is a broad concept and has relationships with almost every concept in **Uses**. It must be noted that all wearable devices have inputs and/or outputs. The relationships exist where inputs and outputs were specifically mentioned in the research conducted. The relationship with **Wellbeing** is centred on the biofeedback collected by wearable devices (especially activity trackers), **Industry** use is focused on augmented reality, **Medical** uses are
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centred around patient monitoring. The relationship with Personal use looks at various methods of input and output.

The model states the relationship between IO and Wellbeing is significant and is based on biofeedback. It should be noted that step tracking and detection of other natural movement is classed as biofeedback in this model. For activity trackers, the collection of biofeedback is generally their main purpose. The literature shows that certain groups of people appear to use biofeedback (i.e. activity tracking) in wearable devices more than others. Studies about biofeedback use (via activity tracking) among young people are mixed (Goodyear et al., 2017, Lindberg et al., 2016). However, older adults with chronic illness tend to use activity tracking wearable devices quite significantly (Mercer et al., 2016). The significance of this relationship is supported by the prevalence of literature about wearable devices collecting biofeedback. The aforementioned research also supports the topical relationship between Biofeedback (within IO) and Activity Tracking (within Wellbeing).

Another highly prevalent relationship is between IO and Medical uses. Medical uses of wearable devices also involve collecting biofeedback (similar to Wellbeing) but are usually more extensive. A large number of wearable devices exist to gather biofeedback about patients in real time for their carers as well as themselves (McWhorter et al., 2017, Naslund et al., 2016, Savur, 2015, Ali and Li, 2016, Ali and Alyasseri, 2017, Emaminejad et al., 2017). These wearable devices have inputs (and sometimes outputs) that are based on feedback from the sensors in the device, and very little conscious input. This makes the relationship between IO and such uses interesting and validates the relationship in the model.

Whilst less prevalent, the relationship between IO and Industry is significant enough to be included in the Usage model. This relationship is based on possible industrial (blue-collar) usage of augmented reality. Although it is not commonly in use yet, there are many studies into the possible uses of augmented reality in an industrial setting (especially with respect to warehouse picking) (Abdüsselam, 2017, Büttner et al., Büyüközkan et al., 2016, Le et al., 2015, McFarlane et al., 2017, Kim et al., 2016c). One interesting use is in the context of assisting maritime pilots with manoeuvring in harbours (Ostendorp et al., 2015). The wide variety of uses (and the unusual interface of augmented reality), validate this relationship in the model.

The relationship between Personal use and IO differs from the other conceptual relationships with IO. This is due to the fact that it is based on a number of different methods of input and
output to a wearable. A number of different methods have been tried to allow users to interact with personal use wearable devices, and the model reflects this. The peer reviewed research also shows this. One particularly interesting study shows an extra four dimensions of interaction added to a smartwatch (Xiao et al., 2014). There are many studies investigating innovative ways to interact with users (Han et al., 2017, Kucukyildiz et al., 2017, Mohammed et al., 2016, Paudyal et al., 2017, Hearn, 2015). These studies show that IO (Input and Output) methods is a factor affecting Personal use of wearable devices, in agreement with the model.

7.3.4. Topical Relationships

![Topical Relationships in the Usage Model – Modified](image_url)

The above diagram shows the topical relationships in the usage model, with two exceptions. The relationship between Biofeedback and Medical, and Biofeedback and Activity Tracking have been removed, as they are covered in the IO Relationships section (section 7.3.3).

These relationships are at the topic level, the lowest level of abstraction from the coded data. Therefore, their specificity makes the relationships not as strong as concept-based relationships.
Privacy has a relationship with Misc. Business in this model, based on data security issues. There are a few studies about data security / privacy and possible misuse of data with respect to wearable devices (Challa et al., 2017, Svantesson, Test, Motti and Caine, 2015, Lowens et al., 2017).

Notifications has a relationship with both Information and Organisation for messages and reminders respectively. Whilst there is little research about specific information and organisation notifications (mobile or wearable), there is a significant body of research into mobile notifications (Hansson et al., 2001, Sohn et al., 2005). There is also research into the context of notifications, which underpins the usefulness of information and organisational notifications. The research mostly covers mobile notifications, but it may be extended to wearable devices (Mateo Navarro et al., 2014, Häkkilä and Mäntyjärvi, 2006).

The relationship between Fashion and Activity Tracking has been studied with respect to the adoption and continued use of wearable devices that allow activity tracking. There are a number of studies that mention this relationship (Dano, 2015, Choi and Kim, 2016, Löfblom, 2017). The Samsung Gear guidelines also say the their wearable should allow the user to express themselves, which may also be construed as an aspect of fashion (Samsung, 2014b, Samsung, 2014a).

The relationship between Activity Tracking and Geolocation is based on the ability of a number of fitness trackers to track where the user has been in addition to their basic tracking functions. Many articles discuss route tracking for workouts, although not usually in a wearable context (Hirsch et al., 2014, Ahtinen et al., 2008, Kalyanaraman et al., 2015).

7.4. Motivation Model

The motivational model is in two sections. For this reason, this section is divided into two parts
7.4.1. Pre-Usage
The main **Pre-Usage** factors are *Positive Motivators, Negative Motivators, Expectations* and *Price*.

*Positive Motivators* and *Negative Motivators* encompass reasons for starting to use (or not starting to use) a wearable. There is a myriad of research in such an area (Basoglu et al., Canhoto and Arp, 2017, Chang et al., 2016, Cho and Park, 2016, Hsiao and Chen, 2017, Rauschnabel et al., 2016, Shih et al., 2015). The research across this broad area supports the conclusion that these topics impact the pre-usage area of motivations with respect to wearable technology.

*Price* is also a significant area in the **Pre-Usage** area of this mode. The model states that the cost of the wearable has a significant impact on its uptake (both positive and negative). The UTAUT2 theory states that price is a significant factor when deciding to purchase technology, and it has been shown to hold with respect to wearable devices (Venkatesh et al., 2012, Cho and Park, 2016). Other research not using UTAUT2 finds that price (with respect to value for money) is a significant factor (Hsiao and Chen, 2017).

Finally, the *Expectations* of the user are described to be a factor when the user is considering purchasing a wearable. It should be noted that these are expected benefits that the user enjoys (which may not eventuate). One study shows that this appears to be true in activity trackers (Shih et al., 2015). Whilst there are few studies purely about users’ expectations affecting their intentions to use a wearable, there are a number of studies that mention the expectations of user in this context, usually about specific expectations (Shin and Hwang, 2017, Udoh and Alkharashi, 2016).
7.4.2. During Usage

![Figure 35 - During Usage Factors](image)

There are three factors that significantly impact the continuing usage of a wearable. The largest factor is the issue of *Abandonment Decision*, followed by the *Benefits* gained by the user and the *Value* that the user believes that they get from the device.

*Abandonment Decision* appears to be a significant issue according to the model. *Abandonment Decision* has been studied with respect to wearable devices, possibly due to the large abandonment rates of fitness trackers (Canhoto and Arp, 2017, Clawson et al., 2015, Coorevits and Coenen, 2016, Lundell and Bates, 2016).

The *Benefits* gained by the use of a wearable is a broad topic, and most research in this area is specific. Some research does suggest that wearable devices provide benefits to sales (Salesforce.com inc., 2015, Scornavacca and Sutherland, 2008). There are many studies with wearable devices in certain situations where benefits are enjoyed (Weaver et al., 2010, Souza et al., 2017, Aromaa et al., 2016).

The *Value* of the wearable as perceived by the user is a significant factor in the continued use of a wearable. A model has been created to calculate the perceived value of wearable devices (Yang et al., 2016). Similar research exists as to the factors that increase the perceived value once a wearable is in use, with respect to the value perceived when deciding to adopt a wearable...
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(Canhoto and Arp, 2017). It is worthy of note that other research does show that perceived value is affected by how innovative the user is (Hong et al., 2017).

7.5. Taxonomy

The taxonomy described in section 3 is based on peer-reviewed literature, so in this section the taxonomy is tested against devices found in the research. To illustrate how the taxonomy works, sections 7.5.1 and 7.5.2 provide examples of how devices (from the peer-reviewed literature) may be classified. Section 7.5.3 shows how the taxonomy may be applied to a device discovered in the research.

7.5.1. LG G Watch R

The LG G Watch R (LG Australia, 2016) is an Android smart watch. As with most smart watches, its primary input is tactile (via a touch sensitive screen) and its primary output is visual (via the screen). Although it may accept voice and gesture inputs and has a tactile output (vibration), these are not the primary methods of interaction.

The device directly interacts with the user, and it’s intended primary function is to tell time. As it comes in multiple colours and supports multiple watch faces, it may be assumed that both fashion and social acceptability were considered in the design (slightly more so than the original G watch, which has a square screen).

The technological aspects of this watch describe other aspects of this wearable. The LG G Watch R can connect via Wi-Fi and Bluetooth to an associated smartphone. Although integration with the iPhone is possible (in a limited manner), it is designed to work with Android smartphones. As an Android smart watch, it runs Android Wear as its operating system. It is powered by an internal rechargeable battery. As a smart watch, it is naturally worn on the wrist. It is currently commercially available. Table 2 provide a summary of the various dimensions of the taxonomy classification of this wearable device.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Input and Output</td>
<td>Primary Input</td>
<td>Tactile</td>
</tr>
<tr>
<td></td>
<td>Primary Output</td>
<td>Visual</td>
</tr>
<tr>
<td>Function</td>
<td>Direct / Supporting</td>
<td>Direct</td>
</tr>
<tr>
<td></td>
<td>Functionality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intended primary function</td>
<td>Keeping Time</td>
</tr>
<tr>
<td></td>
<td>Dependence</td>
<td>Dependent</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Fashion</td>
<td>Considered</td>
</tr>
</tbody>
</table>
7.5.2. **Haptic Sandwich**

The Haptic Sandwich (Spiers et al., 2015), as shown in Figure 36, is an unusual device, but is still able to be categorised under this system. The primary input to the Haptic Sandwich comes from geolocation, which helps the device change shape to direct the user. This functionality means that the device directly interacts with the user. The primary and only function of the Haptic Sandwich is to assist in navigation. The prototype was not designed with fashion or social acceptability in mind. The destination of the user is set via Wi-Fi, and this is the only method of communication that the prototype supported. It did not use an operating system in the general meaning of the term, but for the purposes of the classification, it will be classed as generic. It may be assumed to be system agnostic when it is being programmed. It is held in the hand and powered by a battery. This device was developed as a prototype and is not being developed for sale.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Input and Output</td>
<td>Primary Input</td>
<td>Geolocation</td>
</tr>
<tr>
<td></td>
<td>Primary Output</td>
<td>Feature Change</td>
</tr>
<tr>
<td>Function</td>
<td>Direct / Supporting</td>
<td>Direct</td>
</tr>
<tr>
<td></td>
<td>Functionality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intended primary function</td>
<td>Navigation</td>
</tr>
<tr>
<td></td>
<td>Dependence</td>
<td>Independent</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Fashion</td>
<td>Not Considered</td>
</tr>
<tr>
<td></td>
<td>Social Acceptability</td>
<td>Not Considered</td>
</tr>
<tr>
<td>Technology</td>
<td>Connectivity</td>
<td>Wi-Fi</td>
</tr>
<tr>
<td></td>
<td>Operating System</td>
<td>Generic</td>
</tr>
<tr>
<td></td>
<td>Intended Interoperability</td>
<td>System Agnostic</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>Battery</td>
</tr>
</tbody>
</table>

Table 11 - LG G Watch R Classification

![Figure 36 - The Haptic Sandwich (Spiers et al., 2015)](image-url)
7.5.3. **Fossil Q Founder**

The Fossil Q Founder is a smartwatch described in document D59. As the document did not provide enough information for the device to be classified, the web page from the manufacturer was consulted for the required technical information (Fossil Group Inc., 2019). The classification of this wearable is shown below in Table 11.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute</th>
<th>Possible Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Input and Output</td>
<td>Primary Input</td>
<td>Tactile</td>
</tr>
<tr>
<td></td>
<td>Primary Output</td>
<td>Visual</td>
</tr>
<tr>
<td>Function</td>
<td>Direct / Supporting Functionality</td>
<td>Direct</td>
</tr>
<tr>
<td></td>
<td>Intended primary function</td>
<td>Keeping Time</td>
</tr>
<tr>
<td>Dependence</td>
<td></td>
<td>Dependent</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Fashion</td>
<td>Considered</td>
</tr>
<tr>
<td></td>
<td>Social Acceptability</td>
<td>Considered</td>
</tr>
<tr>
<td>Technology</td>
<td>Connectivity</td>
<td>Wi-Fi, Bluetooth</td>
</tr>
<tr>
<td></td>
<td>Operating System</td>
<td>Wear OS</td>
</tr>
<tr>
<td></td>
<td>Intended Interoperability</td>
<td>Android, iOS</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>Battery</td>
</tr>
<tr>
<td>On-body Location</td>
<td></td>
<td>Hand</td>
</tr>
<tr>
<td>Availability</td>
<td></td>
<td>Commercially Available</td>
</tr>
</tbody>
</table>

Table 11 - Fossil Q Founder Classification

7.5.4. **Conclusion**

In this section, the taxonomy was applied to three wearable devices. The first two devices were found in the literature review, and the third device was discovered during the research project. These three devices were classified successfully, which suggests that the taxonomy may be generalisable for all wearable devices, although more tests are required to confirm this with a high degree of certainty.
8. Conclusion and Future Research

This section sums up the research completed and suggests further research. The research outcomes (section 8.1) are explained, namely the usage model (section 8.1.1), the motivation model (section 8.1.2) and the taxonomy (section 8.1.3). The research questions are answered from these results (section 8.2). Contributions of the research to both theory (section 8.3.1) and practice (section 8.3.2) are explained, as well as the limitations of the research (section 8.4). Suggestions for future research based on information found in this research are given (section 8.5) and finally, a summary of the research is provided in 8.5.3.

8.1. Research Outcomes

This research produced three outcomes, a usage model (section 8.1.1), a motivation model (section 8.1.2) and a taxonomy (section 8.1.3).

The usage model maps the aspects of a wearable to the uses that they have a significant impact on. The motivation model enumerates the factors that encourage users to start using a wearable, and the factors that influence users to continue to use (or to abandon) a wearable. The taxonomy provides a way of classifying wearable devices to allow comparison between said wearable devices.

8.1.1. Usage Model

A model of the factors that impact on various uses of wearable technologies was developed. It was shown that the Wellbeing and Personal uses of a device were impacted on by the Software Experience, Hardware Experience and IO (Input and Output) of a device. Enterprise uses were affected almost exclusively by the Software Experience, whereas Industry and Medical use was impacted mostly by IO. It was also worthy of note that users do not appear to have an issue with interruptions, provided that they are relevant. Finally, Activity Tracking (part of Wellbeing) is related to Abandonment Decision (part of Perceived Value) due to disillusionment when activity tracking does not lead to positive health outcomes. This model is described in more detail in section 6.2

8.1.2. Motivation Model

A model of the factors that motivate users to use wearable devices was developed. The main factors in the uptake of wearable devices are price, fashion and perceived benefits, although the
ability to track activity and receive notifications is also believed to be important. Unobtrusive notifications is the most significant benefit enjoyed by the user once using a wearable. Issues with battery life and comfort are the main causes of abandonment. This model is explained in depth in section 6.3.

8.1.3. Taxonomy

The taxonomy aims to classify wearable devices in a consistent manner. There are six major dimensions: Primary Input and Output, Function, Aesthetics, Technology, On-body Location and Availability. These dimensions (except On-body Location and Availability) have a number of sub-dimensions. Classifying a wearable in this taxonomy allows for comparison of wearable devices, and assists in distinguishing between different types (i.e. comparing apples to apples and distinguishing between apples and oranges). The taxonomy is explained fully in section 3.

8.2. Research Questions

The questions posed in this research consist of one primary research question and three secondary research questions, the answers to which assist answering the primary question. The answers to both the primary question (section 8.2.1) and the secondary questions (section 8.2.1) are given in this section.

8.2.1. Secondary Research Questions

The answer to the primary question is underpinned by the answers to the three secondary questions in this section. The answers to the questions in this section are required to provide an answer to the primary question.

8.2.1.1. What are wearable technologies (wearable devices)?

The definition of wearable technologies as “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body” was answered in section 2.1. The taxonomy (section 3) goes into more depth by having different dimensions used to classify wearable devices. All wearable devices that fit the above definition may be classified within this taxonomy. Non-wearable devices are generally not able to be classified by this taxonomy. One reason is that wearable devices have an on-body location where they are worn and are used (a
dimension of the taxonomy), whereas non-wearable devices do not have such a location, and therefore cannot be classified.

8.2.1.2. How are wearable devices currently used?

The usage model (section 6.2) covers how the elements of the user experience affect various fields of use.

The Hardware Experience, Software Experience and IO (Input/Output) concepts of the User Experience theme are shown to impact on the five main fields of use of wearable devices (Enterprise, Wellbeing, Personal, Industry, and Medical).

The main relationships shown in the model are shown above in Figure 38. Software Experience only has a significant impact on Enterprise use (when integrating with other systems) and Personal use (when mirroring notifications). Hardware Experience also only has two fields of use that it impacts significantly on, which are Personal (Short range communication) and Wellbeing (activity tracking). IO has an impact on four fields of use (not Enterprise,
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interestingly), and is focused on biofeedback (Wellbeing), augmented reality (Industry), and patient monitoring (Medical). The relationship between IO and Personal exists due to the various input methods mentioned with respect to personal use wearable devices.

8.2.1.3. Why do users use wearable devices?

![Motivation Model Diagram]

**Figure 39 - Motivation Model**

The motivation model (section 6.3) explains why users use wearable devices. The model shows the motivations behind using wearable devices, in essence the “why” users choose to use a wearable, and why they continue to use a wearable once they have started to use a wearable.

This model enumerates the factors that motivate users to adopt wearable devices, and the factors that encourage users to continue using a wearable. This distinction is shown above in Figure 39. The pre-usage and during usage factors do not have any significant relationships between them, which demonstrates that the factors to start using a wearable and the factors to continue use of a wearable are significantly different.
8.2.2. Primary Research Question

The answer to the primary research question “What elements affect the adoption and usage of wearable technology?” is twofold, and is found in the motivation and usage models created in this research. The answers to the secondary questions assist in answering this question.

The first secondary question must be answered before the other two. It is not possible to describe how and why wearable technologies are used without determining what wearable technologies are. For this purpose, a definition and a taxonomy were developed. The definition: “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body” provides a basic definition, and the taxonomy created extends the definition by allowing classification of wearables. This clear definition allows the answering of the two other secondary questions.

There are two sets of elements that affect the usage of wearable technologies. They are the user experience and the motivations behind the use of wearable devices. Which aspects of the user experience affects the usage depends upon the use case of the wearable (as the usage model has investigated). The motivations behind the usage of wearable devices differ depending on whether the user is considering the use of a wearable or if they already are using a wearable. The motivation model explains these motivations.

The motivation model is a hierarchical model, which describes the aspects that affect the uptake and the continued use of wearable devices as a whole. This model provides a broad answer to this question, identifying the aspects that affect the decision to use, and the decision to continue using, wearable technologies. For example, it has been shown that price is a factor in the decision to start using a wearable, but the price paid for a wearable does not affect a user’s decision to continue using a wearable.

The usage model is a relational model which provides information about the relationships between the user experience and various fields of use. This model provides an answer more specific to fields of use of wearable devices, in explaining which uses of wearable technology are affected by other aspects of the user experience. One such example in the usage model is the relationship between IO (Input and Output) and the Industry field of use. This relationship has been shown to be prevalent, in the field of Augmented Reality.
8.3. Contributions of the Research

This research makes two contributions to both theory and practice, and one contribution purely to practice. Section 8.3.1 justifies how the usage (section 6.2) and motivation (section 6.3) models provide the contributions to theory of this research. Section 8.3.2 explains how these models, as well as the taxonomy created in section 3 may be applied in a practical manner.

8.3.1. Contributions to Theory

The two models, the usage model (section 6.2) and the motivation model (section 6.3) provide a contribution to theory in this research. Both of these contribute to research in the field of user experience with respect to wearables.

The usage model is a theory which shows which aspects of the user experience have a significant effect on various fields of use. At the time of writing, no such model was known to exist. Other models of wearable usage exist (Rincon et al., 2017, Bowen et al., 2015, Angulo et al., 2016), but only with respect to individual wearables, not over a range of wearables. This contribution to theory provides a new model. One such example of the contribution to theory is the discovery that short-range communication (e.g. NFC), which is part of the hardware experience has an impact on the personal field of use, more so than any other field of use.

The motivation model is also a contribution to theory. Whilst studies have been done on specific wearable adoption and abandonment, no model has been created specifically for wearable technology. This model is more specific than the UTAUT2 model (Venkatesh et al., 2012), but is less specific than other studies that investigate uptake/continued use of specific wearable devices (Rauschnabel et al., 2016, Wu et al., 2016). That makes the motivation model new to theory.

8.3.2. Contributions to Practice

All three research outcomes demonstrate a contribution to practice. The usage model (section 6.2) and the motivation model (section 6.3) may be used in the design of wearable devices (software and hardware). The taxonomy (section 3) may be used with existing wearable devices to allow comparison and classification of said wearable devices.

The usage model is useful to designers of wearable software and hardware. In the case of hardware design, the model provides information as to what aspects of hardware influence the usability of the wearable (with respect to the use case). This allows designers to focus on the
areas of hardware that have the greatest impact on the fields of use of the wearable under design. Software designers also benefit from the usage model in the same manner, as the model allows them to determine which aspects of the software experience have significant effects on the intended use case of the software.

The motivation model provides similar benefits to the usage model, but the benefits are more significant with respect to hardware design. Knowing which aspects entice a user to start using a wearable and which aspects promote continued use can improve the design of wearable devices. This information allows developers to design their hardware and operating systems to promote uptake and continued use. Focusing on aspects described in the motivation model allow more appealing wearable devices to be created and reduce abandonment of wearable devices.

The uptake section also may assist marketing of a wearable, and the continued use section may inform software developers of what kind of apps are likely to be desired by wearable users.

The taxonomy is not very useful in the design phase of wearable devices, but it is useful once a wearable has been completed. The dimensions of the taxonomy allow a standardised classification that may be applied to any wearable technology. When a person or organisation is deciding to use wearable technology, they may use this taxonomy to filter out wearable devices that do not meet their needs, and compare ones that may in a standardised manner, to find the optimal wearable or wearable devices for their needs.

8.4. Limitations of the Research

A number of limitations affected this research. The low number or participants and the lack of diversity of both participants (all early adopters) and wearable devices (all wrist mounted) affected the qualitative interviews, as did the fact that all interviewees lived in the same country. The document analysis was limited by the inherent untrustworthiness of grey literature and the inability to ask for clarification of statements.

The Qualitative Interviews (section 4.4) conducted only included Twenty participants. Efforts to recruit more participants proved unsuccessful. All the participants had to use or have used a wearable device, preferably more complex than a simple activity tracker. These participants were expected to be innovators or early adopters of technologies, as described in the Rogers Adoption Curve (Rogers, 2010). The small cohort was varied in their professions, which makes corroboration of the data difficult. This limitation mostly affected the usage model and could be
overcome by having a larger cohort, although the smaller number of participants may still provide adequate information and may also allow for deeper analysis (Sandelowski, 1995). In this case, the results showed that theoretical saturation may have been reached. Studies show that theoretical saturation can occur in under 15 interviews (Guest et al., 2006).

As mentioned earlier, at the time of the research wearable devices were in the “early adopter” stage (Rogers, 2010), meaning that the majority of people did not own a wearable device. This may skew usage of and motivations to use and continue using wearable devices, as different groups of users may have different experiences.

Another sampling limitation is the lack of diversity of wearable devices in the interviews. All participants used wrist-mounted wearable devices. The vast majority of documents analysed also were about wrist-mounted wearable devices. Whilst the majority of consumer wearable devices are wrist-mounted, it may adversely affect the results of the data analysis.

The fourth limitation of the interviews was the fact that all the interviewees lived in Australia. Whilst this limitation is ameliorated by the documents in analysis coming from other countries, it is still worthy of note.

Document Analysis (section 4.4.4) contained limitations due to the use of Grey literature (section 4.5.1). A large amount of grey literature (literature that has not been subjected to peer-review) exists regarding wearable technology, and it was used in this research. Whilst this information is useful, the veracity of the data may be called into question. In an effort to mitigate this, information had to be corroborated by at least 2 independent sources for it to be deemed reliable. This still allows for incorrect or unreliable data to be used in the research, possibly altering the results. To remove this limitation, further research could have been done into the authors of the literature to determine the reliability of their articles. Ideally, these authors may agree to participate in qualitative interviews, allowing more structured data collection. This possibility was not explored during the research.

### 8.5. Suggestions for Future Research

During the course of this research, other areas that warrant research were discovered. Research in these areas may be very useful and there appears to be little research in these areas. Work-Home interference by multi-purpose wearable devices (section 8.5.1) research would explain how wearable devices can cause work life to infringe upon time at home, and research into
Offloading processing of wearable data (section 8.5.2) could improve efficiency of wearable devices by determining when/whether information is better processed on the device, or uploaded to the cloud for processing.

8.5.1. **Work-Home interference by multi-purpose wearable devices**

Many wearable devices are designed to be worn all day by the user, both at home and at work. This can impact on the work-life balance of users in the same manner that mobile devices can (known as work-home interference or WHI). Literature with respect to the WHI issues created by mobile devices is covered in section 2.4.

The prevalence of BYOW (Bring Your Own Wearable) in the workplace (Salesforce.com inc., 2015) shows that this is a growing trend. No research has been found on the impact of wearable devices with respect to WHI, and the results may have a significant impact on software and operating system design for wearable devices.

8.5.2. **Offloading processing of wearable data**

As wearable devices usually have limited power (both processing and battery), processing of wearable data must be efficient. Mobile devices are also limited in power, although to a lesser extent than wearable devices.

To lower the amount of power required in mobile devices, it has been suggested that any intensive processing be done in the cloud, where resources are less constrained (Liu et al., 2013). With the significant constraints that exist with many wearable devices and the increasing power of mobile devices, wearable devices could allow a large amount of intensive processing to be handled either on a mobile device or in the cloud. On the other hand, transmission of data over wireless systems can be power-intensive. The power used in transmission of extra data may outweigh the savings, but this has not been investigated.

No research was found in this area, although such research could lead to extra battery efficiency in wearable devices, where battery life is known to be a concern of users.

8.5.3. **Recreate study with larger and more diverse cohort**

In this research, only twenty participants were interviewed, all using wrist-mounted wearables. Due to this, grey literature had to be used to allow the results to be significant.
A Usage and Motivational Model for Wearable Technology: A Users' Perspective

A larger study would eliminate the need for grey literature, and allow original experiences to be used as the only data source. Additionally, finding users with culturally diverse backgrounds and/or using different types of wearables (not just wrist-mounted) may also lead to more significant findings.

Additionally, a larger study may allow for other methods of testing importance of relationships. Consequentiality of relationships could be used to determine importance. This was not done in this study, but further studies may investigate this.

### 8.5.4. Deeper research into relationships in usage model

Further research into the relationships shown in the usage model could be conducted. The relationships currently are shown to exist, and the main common issue shown in the data is provided. Some relationships (and lack thereof) exist that are not entirely clear, the lack of a significant relationship between IO and Enterprise being a notable example.

Subsequent research could investigate why these relationships exist (or do not exist). The usage model only states that they do exist and provides the factor of that topic/concept that provides the relationship. It does not investigate why the relationship exists, only that it does.

### 8.5.5. Research into specific fields of uses

This research project has shown that wearables are a heterogenous group, and therefore studying them as a whole may not yield as much useful research as studying sub-sets may be. For example, the fashion aspect of wearables may be studied, but industry wearables should not be included in such a study because fashion is not a significant factor in the industry field of use.

Research into individual fields of use may yield different results to this research, as fields of use are nuanced, and different sub-fields may provide new insights. Different levels of abstraction of the data may provide information that is missed in a broader study.

### 8.6. Summary

This subject of this thesis was: A Usage and Motivational Model for Wearable Technology: A Users' Perspective. The objective of the research was to answer the primary question “What elements affect the adoption and usage of wearable technology?”. This is a complex question,
A Usage and Motivational Model for Wearable Technology: A Users' Perspective

and therefore the three following questions were developed to assist in answering the main question:

1. What are wearable technologies (wearable devices)?
2. How are wearable devices currently used?
3. Why do users use wearable devices?

A number of methods were proposed for use in this research, and Grounded Theory (Shackel, 1984) was decided on as a way to develop theories. The process by Eisenhardt (1989) was used. The literature reviewed before the research was conducted allowed a taxonomy to be created, which provides a multi-dimensional way to classify any wearable technology. The definition used for wearable technology in the taxonomy creation is “Always-on, peripheral interaction, context-aware mobile devices that may be easily worn or carried on one’s body”. This taxonomy provides an answer to the first secondary question.

Twenty participants were interviewed about their experience using wearable devices (wearable technologies) and a large amount of “grey literature” about experience with wearable devices was also analysed. The literature and transcripts of the interviews were coded, and codes that were similar were grouped into Topics. The Topics were abstracted into Concepts, from which three Themes emerged (User Experience, Uses and Perceived Value). Due to the low number of Topics in Perceived Value, Concepts were not used, and Topics were linked directly to the Theme.

The relationships between User Experience and Uses formed the basis for the usage model. This is a relational model, which shows how certain aspects of the user experience affect different fields of use. Links were made at all levels of abstraction in the creation of this model. This model answers the second secondary question.

The theme Perceived Value allowed the creation of a hierarchical model. The data in the topics allowed a model of the motivation to use wearable devices to be created. This model has two sections, Before Usage and During Usage, as it transpires that the motivations that encourage users to start using a wearable are different from the motivations that make the user continue to use (and not abandon) the wearable. This model provides an answer to the final secondary question.
9. Appendix A – Taxonomy Wearable devices

This section lists the wearable devices considered in alphabetical order, grouped by availability. Some wearable devices do not have names. In this instance, the semantic “name” for the wearable is provided in parentheses.

9.1. Commercially Available

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9.2. Under Commercial Development

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## 10. Appendix B - Topics

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Table 12 - Topics in Alphabetical Order
11. Appendix C - Participant Information and Consent Form

The participant information and consent form may be found on the following pages. Please note that the title of the project has changed since the interviews were conducted.
INVITATION TO PARTICIPATE IN A RESEARCH PROJECT

PROJECT INFORMATION STATEMENT

*Project Title:* The Uses and Usability of Wearable Technologies in Business

*Investigators:*
- Hayden O’Sullivan (PhD Candidate, School of Business IT & Logistics, RMIT University, contact details redacted)
- Dr. Vince Bruno (Supervisor, Lecturer, School of Business IT & Logistics, RMIT University, contact details redacted)
- Dr. Martin Dick (Associate Supervisor, Senior Lecturer, School of Business IT & Logistics, RMIT University, contact details redacted)

*Introduction*
You are invited to participate in a research project being conducted by RMIT University in the School of Business Information Technology and Logistics. Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate. If you have any questions about the project, please ask one of the investigators.

*Project Details*
This research is being conducted as part of a PhD program which is being undertaken by Hayden O’Sullivan (with Dr. Vince Bruno as supervisor). This project has been approved by the School of Business Information Technology and has received ethical approval.

This project is investigating how wearable technology is used in business, and how easy it is to use it. Wearable technology means any technology that can be worn. Common examples of this are activity trackers and smart watches. Other wearable technologies include smart fabrics and heads-up displays such as Google Glass. The data that is collected will be used to discover where wearable technology is used in business, where it could also be useful and how to make it easier to use.

The main research question being answered is:

*What are the key elements that affect the usability of wearable technologies from a business perspective?*

This question will be answered via a number of interviews, and via studying literature about experiences with wearable technology (e.g. blogs).

Participants of this study have been invited to volunteer some time to discuss their experiences with wearable technology. These participants have been approached via companies or professional organisations. These participants have been invited to participate because they have experience of using wearable technology in a business environment.

*Procedures/Risks*
Participants will be asked to participate in a semi-structured interview, for approximately 1 hour, where discussion will take place about their experiences with wearable technology in a business environment. This discussion may include examples of good and/or bad experiences with wearable technology. The interview will be recorded (audio only) and the participant (you) may terminate the interview at any time.

No risks are apparent from participating in this research. The interview will only discuss professional experiences. If you (the participant) are unduly concerned about the questions or
the responses given or find participation distressing, you may ask the interviewer to either remove that discussion/question and answer from the record, or you may terminate the interview. The researcher will be happy to discuss any concerns with you confidentially. You are under no obligation at any time to participate (or continue to participate) in this research.

Participation in this project will benefit users of wearable technology, by suggesting improvements to usability. The participant may be offered any outcomes of the research by the researcher.

What are my rights as a participant?
- The right to withdraw from participation at any time
- The right to request that any recording cease
- The right to have any unprocessed data withdrawn and destroyed, provided it can be reliably identified, and provided that so doing does not increase the risk for the participant.
- The right to have any questions answered at any time.

Privacy and confidentiality
All data that is recorded will be transcribed and encrypted. This data will be kept on the primary researcher’s computer during the research, and may be backed up on secure offsite data storage (the cloud). It is required that all data be kept of 5 years upon completion of this project. After this time, all data will be destroyed. This data may be published in an anonymous manner.

Any information that you provide can be disclosed only if (1) it is to protect you or others from harm, (2) if specifically required or allowed by law, or (3) you provide the researchers with written permission.

Queries
You can contact the primary investigator (Hayden O’Sullivan – contact details redacted) or his senior supervisor (Dr. Vince Bruno - contact details redacted) if you have any questions.

Yours Sincerely

Hayden O’Sullivan
Bachelor of Information Technology (Hons)

Dr. Vince Bruno
Doctor of Philosophy in Computing

Any complaints about your participation in this project may be directed to the Secretary, Portfolio Human Research Ethics Sub Committee, Business Portfolio, RMIT, GPO Box 2476V, Melbourne, 3001. The telephone number is (03) 9925 5994 or email address rdu@rmit.edu.au.
Details of the complaints procedure are available from the above address or http://www.rmit.edu.au/secretary/hec.
CONSENT FORM

1. I have had the project explained to me, and I have read the information sheet

2. I agree to participate in the research project as described

3. I agree:
   - to be interviewed
   - that my voice will be audio recorded

4. I acknowledge that:
   (a) I understand that my participation is voluntary and that I am free to withdraw from the project at any time and to withdraw any unprocessed data previously supplied (unless follow-up is needed for safety).
   (b) The project is for the purpose of research. It may not be of direct benefit to me.
   (c) The privacy of the personal information I provide will be safeguarded and only disclosed where I have consented to the disclosure or as required by law.
   (d) The security of the research data will be protected during and after completion of the study. The data collected during the study may be published, and a report of the project outcomes will be provided to Dr. Vince Bruno, Dr. Martin Dick and Mr. Hayden O’Sullivan. Any information which will identify me will not be used.

Participant's Consent

Participant: ____________________________ Date: ____________________________

(Signature)

Participants should be given a photocopy of this PICF after it has been signed.
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