IDENTIFYING PRINCIPLES OF HUMAN–COMPUTER INTERFACE IN IOT DEVICES: A SOUTH AFRICAN CONTEXT

by

Saman Waqar
U16185952

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Study leader:
Prof H Smuts

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ABSTRACT

With an increasing number of households implementing smart home technology in South Africa, it is important to understand if the Internet of Things (IoT) devices are enhancing the user's quality of life as well as meeting their needs and expectations. Identifying and incorporating the Human–Computer Interaction (HCI) component when building an IoT device can assist with ensuring that the smart device meets the useability requirement and addresses the challenges and concerns raised by end users. As the end user is required to install and manage the smart device by themselves, the smart device manufacturers must ensure that these devices are easy to set up and can be managed by both technical and non-technical users. IoT devices require data to be fully functional and perform their necessary tasks. IoT data collection is an ongoing discussion as the end user might not be entirely comfortable with the collection and sharing of their personal home data with device manufacturers. HCI designers, therefore, are required to consider end users' emotions regarding their security concerns.

Hence, the purpose of this research is to study the principles of HCI in an IoT device. The objective is to add to the existing body of knowledge related to building computation devices around HCI principles. This interpretive case study used two qualitative data collection methods to answer the research questions: a questionnaire and semi-structured interviews. The questionnaire focused on gathering insights into the current user experience with smart home devices and identifying challenges or concerns raised by the device users. The semi-structured interviews focused on gathering information on the inclusion of HCI when designing an IoT device, IoT data and the IoT security element, from the employees of the organisation in the case study.

The research findings indicated that while the participants have adapted to installing and managing their smart home devices, there were several usage challenges and concerns that need to be addressed. Several of the research participants were unaware of the smart device collecting usage data and therefore, the requirement to educate end users on data collection and usage is highlighted in the study. Key design components of the IoT were highlighted by the interview participants and several methods were also suggested to enhance the user experience of IoT devices.

Keywords:

IoT, smart home, HCI, user-centric, user experience, IoT data, IoT security and IoT design

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION

As we move towards a more digital and connected world in the 21st century, the need to be connected anytime and anywhere is becoming more prevalent. This request is not only limited to smartphones but also includes an individual’s everyday 'objects' to be connected as well as provide real-time solutions to everyday problems. The term Internet of Things (IoT) was first introduced in the late 1990s and according to Olson et al. (2015), it was a very similar concept to ubiquitous computing. Ubiquitous computing can be defined as a society in which Human–Computer Interaction (HCI) can be incorporated effortlessly into the everyday life of an individual but in time, the IoT term came to encompass more capabilities and functions than ubiquitous computing. As explained by Andrade et al. (2017), Ubiquitous computing's main focus is on the Human-Thing interaction which centers around seamlessly integrating into a human’s life and providing services in the background while the IoT encompasses more than one type of interaction. These interactions are Thing-Thing and Human-Thing interactions. The Thing-Thing interaction is an interaction that does not require user involvement and requires objects to communicate with each other to provide services to the users. The complexity and issues arise in the Thing-Thing interaction which has an impact on the user experience. These issues include responsive, reliability, context-awareness and interoperability, etc.

The summarised definition of the Internet of Things (IoT) provided by Ndubuaku and Okereafor (2015:23) is:

> The Internet of Things (IoT) refers to the use of intelligently connected devices and systems to harness data gathered by embedded sensors and actuators in machines and other physical objects. (Ndubuaku & Okereafor)

The ‘Thing’ in the IoT is a term can either be a physical object (e.g., a smart watch) or a virtual entity (e.g., Apple Inc.'s Siri) (IBM, 2021). IoT devices are enabled by using radiofrequency technology which allows the object to be uniquely identified and managed by a computer (Nunes et al., 2015).

The term HCI was previously known as man–machine interaction and it was introduced in the early 1980s (Ebert et al., 2012). The international HCI society, the Association for Computing Machinery (ACM) and Special Interest Group on Computer–Human Interaction (SIGCHI) (Hewett et al., 1992:5) define HCI as "Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them". Some of the characterisations of the Human-Computer Interaction (HCI) field that are highlighted by the Association for Computing Machinery (ACM) are concerns around the combined efforts of human and machine in relation to the completion of a task; the capabilities of a human to use a machine, which includes the ease of use of the machine interface; and the communication process between a machine and a human being.

As highlighted in the HCI definition, it is important to consider the human factor when building a computing system for software or for a machine to be deemed a success. A computing system is not only limited to a desktop computer, but can also be extended to define a device that uses computation power to complete a task. Over the years, HCI has been broken down into three generations and Norman (2018) has declared that we are currently in the third generation of HCI. The third generation of HCI requires a user to be connected via a device to the internet at any time and from anywhere in the world. Gone are the days when we had to wait for a certain time to complete a task (e.g., making a payment or shopping). With the power of the internet and rising demand for being connected at all times, people's lives have become enhanced with the introduction of new technologies.

Since the IoT devices are built *by* humans to simplify daily tasks and activities *for* humans, it is very important to include the user's needs and wants when building an IoT device. A large amount of research has focused on how we enable and implement IoT devices (Čolaković & Hadžialić, 2018) but as stated by Nunes et al. (2015), the end user is still considered an external entity and an unpredictable component of the control circle.

1.2 PURPOSE OF THE STUDY

The purpose of this research is to study the principles of HCI in an IoT device. The objective is to add to the existing body of knowledge related to building computation devices around HCI principles. The focus was around computer literate participants using household IoT devices who make use of smart home gadgets and the employees of the case study's organisation who have been involved in information technology (IT) product designs.

1.3 PROBLEM STATEMENT

The main driving forces for the adoption of IoT technology is that it provides convenience (Nolin & Olson, 2016) and connectivity (Zheng et al., 2018) capabilities to the end-users. Despite numerous benefits provided by the IoT devices, users are still slow to adopt the technology and as highlighted by Bansal et al. (2020), the reason for the slow adoption is data-related issues which include the processing and management of IoT data. The other concerns raised by end users regarding the IoT devices usage are around trust, understanding collected IoT data (Nuamah & Seong, 2017), privacy issues related to the collected data (Ammari et al., 2019) and management of IoT devices in a smart environment (Nazari Shirehjini & Semsar, 2017).Sensor used by IoT devices generate a huge amount of data and analysing that data can lead to additional processing load on the user's side (Nuamah & Seong, 2017). The above concerns were raised and highlighted as it can lead to a negative user experience and hinder the successful implementation of Internet of Things within an environment.

Past literature has focused on the enablement and implementation of IoT devices (Čolaković & Hadžialić, 2018) and some research on user perceptions of Internet of Things (IoT) devices has been done (Zheng et al., 2018). Despite the existing research, Čolaković & Hadžialić (2018) highlighted that the IoT raw data visualisation problem needs to be resolved in a way that supports end-user needs. The user interface for the visualisation of IoT raw data should be displayed in a manner that puts less cognitive load on the user. As requested by Koreshoff et al. (2013), future research should focus on the application of an IoT framework designed by (Atzori et al., 2010) on different use cases and as part of this research paper, an analysis was conducted on different HCI frameworks proposed for IoT technology.

Based on the data collected by Statista (Holst, 2021), the number of connected IoT devices will almost triple from 8.4 billion in 2020 to more than 25.4 billion by 2030. South Africa's IoT market is expected to grow at a robust 20.96% annual growth rate from 2020 to 2025 (IndustryARC, 2021). With the rise of IoT devices in the upcoming year, Jakobi et al. (2018) argue that when designing a smart home device, much focus should be on the user's needs and wants since the end users become the system administrators for these gadgets. According to Moreno et al. (2013), Human–Computer Interface (HCI) principles are imperative for building useable and enhanced systems, and when building an IoT device for consumers and industries, HCI principles should be taken into consideration because humans play a vital role in the usage of IoT technology. As smart devices and gadgets are being utilised and appreciated by the end user, the manufacturers of the IoT devices must ensure that the gadgets recognise users' intentions and fulfil the needs of the end user (Lytras et al., 2013).

For this research paper, the focus was on identifying the principles of HCI in an IoT device. The sub-problem can be divided into:

- Benefits and challenges of using IoT devices in a daily context.
- Security and privacy concerns related to the IoT device.
- Access to information produced by IoT devices.
- Presentation of IoT raw data to the end user.

1.4 RESEARCH QUESTIONS

In this research study, the following main question was investigated:
What are the principles of Human–Computer Interface in IoT devices?

The following sub-questions were addressed in the research:

- What is the user's motivation for purchasing an IoT device?
- What are the user's concerns regarding data collection and privacy?
- How is information related to IoT device usage represented to the end user?
- What are the challenges of IoT devices in relation to Human-Computer Interaction (HCI)?

- What components are considered for designing an IoT device?

Academics who are interested in conducting research on designing IoT devices for end-users would benefit from this study. In addition, this research paper gives context to the current user perceptions and the challenges faced by smart home device users. IoT specialists and HCI practitioners could also benefit from this study by designing IoT devices that meet end-user needs concerning the useability of the devices.

1.5 RESEARCH METHODOLOGY

Research methodology describes the process of how a researcher investigates the research questions (Oates, 2006). This researcher selected Interpretivism as a research paradigm. Interpretivism is an adequate choice for this research as it allows the researcher to understand how a person or group perceives their world; hence, to answer the research question, the study aims to comprehend and identify the end user's perception of IoT devices. Based on the selected paradigm, a qualitative research approach was selected to conduct the study. A qualitative research approach can assist in comprehending an individual’s perception of a technology product (Clemmensen et al., 2016). The motivation for selecting a qualitative research approach is that it assisted with comprehending the identified phenomena in detail. The research strategy selected for this study is a case study approach. The motivation for selecting a case study is because a specific type of smart IoT device and location was used to investigate the implementation and effectiveness of Human-Computer Interaction (HCI) principles on IoT devices. The selected participants were the computer literate participants using household IoT devices as well as employees of the organisation in the case study who may be involved in designing an IoT device.

A non-probabilistic sampling method was used to select the two types of participants for this study: smart home device consumers and employees of the organisation that serves as the case study. A triangulation method was used to gather the required data for the study and two data collection tools were used, namely questionnaires and semi-structured interviews. Two sampling methods were selected for the research study: self-selection and quota sampling. The sample size for the questionnaire was 57 and 10 organisation employees were interviewed. The researcher employed a cognitive interviewing strategy to pre-test the questionnaire with a test sample. This strategy has been widely used to evaluate the quality of a survey (Willis, 2005). To analyse the collected data, Creswell's data analysis spiral method (Brent & Leedy, 2015) was used to analyse the collected data in this research study. This method allows a qualitative researcher to go through the dataset a few times.

1.6 ASSUMPTIONS

In this study, the following assumptions were made:

- The data-gathering process consisted of questionnaires being distributed and interviews being conducted virtually due to the current global pandemic which required social distancing. The assumption was made that these data collection methods would be administered by digital means.
- The research participants would possess smart devices and be familiar with those devices.

1.7 LIMITATIONS

This research study mainly focused on human interaction with IoT devices and contributes towards the existing body of knowledge on HCI. The study did not focus on the detailed technological design, enablement and implementation of IoT devices. Only South African consumers and organisations were selected as research participants from whom to collect the required data.

1.8 BRIEF CHAPTER OVERVIEW

This chapter included details on the background and purpose of the study as well as the problem statement, research questions, assumptions and limitations related to the research study. In summary, Chapter 1 shed light on the existing problem concerning the management of an IoT device and the justification for conducting this study.

Chapter 2 comprises the literature review for this research study. The literature review was conducted by reviewing peer-reviewed research papers and academic books. It identifies themes and topics in the existing body of knowledge related to Human-Computer Interaction (HCI) principles and IoT devices.

Chapter 3 presents the research methodology that was used in this research study. This chapter includes details on which research design, sampling, pre-testing and data analysis methods were used to obtain answers to the research questions.

An analysis of the findings of the research is presented in Chapter 4. It includes details on the implementation of the research methodology defined in Chapter 3 and the data analysis method used to obtain results for the research study.

Chapter 5 highlights the key findings of the research study and includes concluding remarks. This chapter summarises the research study by describing the findings, contributions and recommendations for future research related to the research study.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The objective of a literature review is to demonstrate that the researcher is conscious of the existing body of knowledge on the chosen topic, explain the theories that could be used in the data analysis steps and identify issues/problems that might need to be addressed by the research community (Oates, 2006). In this research, an existing body of knowledge was reviewed to answer the current research question.

2.2 HCI DESIGN PRINCIPLES AND RULES

Design principles provide guidance and suggestion to designers when building useable objects. These principles are extracted from various theories, common-sense and experience. Several design principles and rules have been formulated over the years (Preece et al., 2002). In this literature review, the focus was on the design principles by Don Norman and the 'golden design rules' suggested by Shneiderman (Shneiderman, 2004). When building an IoT device, the designer must build devices that will assist in fulfilling the users' goals without causing them any distress. Norman, (1998) designed the principles described in Table 1. These principles can assist in building effective objects:

Table 1: Norman's Design Principles

Principle	Description
Discoverability	The purpose of this principle is to assist the end user in comprehending what action can be performed by an object.
Affordance	This principle denotes the association between a physical object and the end user. Affordance focuses on the useability of a physical object and what actions can be performed by the object.
Signifier	The purpose of this principle is to guide the end user on how to utilise an object. Designers include clues and instructions to simplify and assist the user in using the object. Signifiers are more vital than affordance as they guide the end user on how to use the actual object.
Mapping	This principle focuses on the association between a specific control and the result of that control in the world. A quality designer would take into

	consideration how a human behaves.
Feedback	The purpose of this principle is to communicate with the end user about the result of an action. Feedback must be provided in real time because causing a delay in feedback could frustrate an end user. Feedback must be planned for every action that an object could perform and must be informative. Feedback can be presented as audio, visual or a mixture of both.
Conceptual Model	Also known as the mental model, this principle refers to explaining how an object operates. The model is constructed based on the end user's comprehension of how a specific object operates. The conceptual model might differ from person to person and it relies on an individual's prior experience with an object.
Constraint	This principle refers to the limitations or restrictions of an object. Certain objects can only perform certain actions and that limits their usage. There are four types of constraints: logical, cultural, physical and semantic.

In a research by Urquhart and Rodden, (2017), three key concepts by Norman that can assist the designer with designing interactive devices are discussed. These concepts are: affordance, signifiers and mental models. These concepts are briefly described in the section above (Table 1). If a user is unable to utilise a product, the product designer is either blamed for ineffective communication with the users or not fully understanding the users need. In a study conducted by Cruickshank & Trivedi (2017), the integration of IoT devices with Norman's design principle was discussed. As IoT devices includes an autonomous aspect to it, designers are now requested to consider machine to machine interaction as well as human to machine interaction. A user can be identified as 'smart objects' within IoT design process. These smart objects can be human or non- humans.

Ben Shneiderman also constructed eight golden rules for a physical design that could aid in building useable devices and softwar (Yusof et al., 2004). These eight golden rules are described in Table 2 (Preece et al., 2002):

Table 2: Shneiderman Golden Rules

Golden Rule	Description
Strive for consistency	This rule refers to providing consistent terminology e.g., menus, actions and process flow for a system. For example, similar actions trigger across smart home devices from the same brand.
Offer informative feedback	This rule refers to providing valuable feedback to the end user based on their actions. The feedback message text can differ from user to user based on their role or access level to the system
Enable users to use shortcuts	This rule refers to providing shortcuts for end users to perform an action on the system. The purpose of these shortcuts is to save users time in performing the action.
Design dialogue to yield closure	This rule refers to providing closure to the end user when an action has been completed successfully. An example of smart devices could be lighting up an icon on the device itself or providing a success message on the smartphone controlling the device.
Simple error handling	This rule refers to building a system or smart tool that is accepting of errors made by the user and provides simplified solutions for fixing them. The system should provide sufficient support to end users.
Prevent easy reversal of actions	This rule refers to providing options to undo recent actions on the system. By providing this function, the user can explore different functionalities provided by the system.
Support internal locus of control	This rule refers to providing the required control to the end user for using the device. End users feel more comfortable if they control the device.
Reduce short-term memory load	This rule refers to making the system as simplified as possible and reducing the memory load on the end user. The end user should not have to rely too heavily on their short-term memory to use a system or smart device.

It is imperative to design a product that is centred on users' interests, called a user-centred design (UCD). By situating the end user at the centre of the design process, device designers can ensure that the useability criteria have been met as the user is 'involved' in different stages of a product development cycle. The useability criteria addresses the following elements in the product evaluation process: safety, efficiency, learnability, effectiveness, utility, and memorability (the amount of time it takes a user to remember how to perform a common task) (Abras et al., 2004). User-centred design includes three main principles that can be used in product design and development. These principles include focusing on end users and tasks, measuring usability empirically, and, designing and testing usability iteratively (De Vito Dabbs et al., 2009)

The level of activity required by the end user to interact with a machine must be carefully considered. There are three different levels of user activity: the first level focuses on the physical element which includes the interaction between the end user and the machine, the second level focuses on the cognitive element which deals with how an end user comprehends the system and the third level focuses on the affective element that not only deals with the user experience of the machine, but also focuses on ensuring that the end user will continue using the machine (Karray et al., 2017). As mentioned by Ferre et al. (2005), useability is a critical element that needs to be included in a software product development process. A product is considered useable when the end user can effectively achieve their goals and are satisfied with the product.

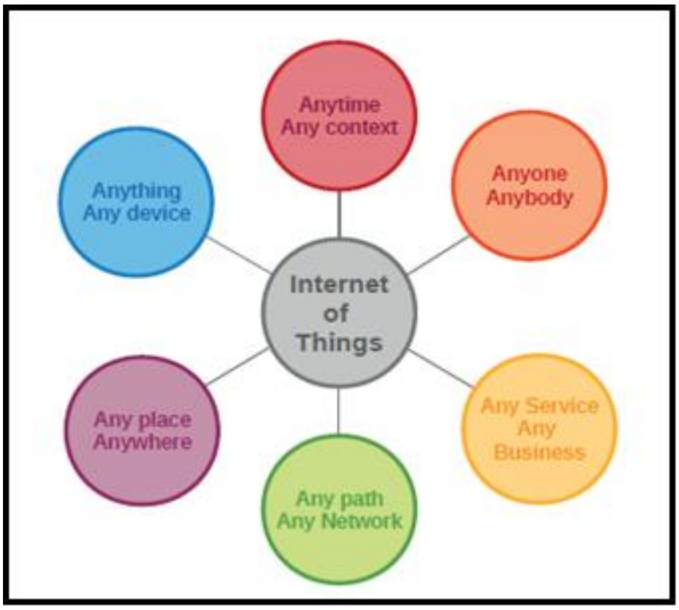
As mentioned by Karray et al., (2017), a machine designer must identify the type of Human-Computer Interaction (HCI) design that will be used to build the device. The two types of HCI designs that should be considered by the designer are Intelligent HCI design and Adaptive HCI design. Adaptive HCI designs are the opposite of Intelligent HCI designs as they are passive and may not make use of the intelligence element to build the interfaces. An example of Adaptive HCI design is an e-commerce website that uses a graphical user interface (GUI) to interact with the end user. Intelligent Human-Computer Interaction (HCI) design uses a level of intelligence to create user interfaces. An example of Intelligent Human–Computer Interaction (IHCI) design is making use of visuals to track a user’s physical activity (Karray et al., 2017). Intelligent Human–Computer Interaction

(IHCI) enables ubiquitous computing by adjusting the user interfaces which can assist in meeting the end user’s needs and wants (Duric et al., 2002).

2.3 IOT PURPOSE

As highlighted by Perera et al. (2013), the IoT has been a trending topic of discussion within the industry and academic space. The reason behind the interest is the type of functionality that the technology can provide. The IoT aims to create a world where many smart objects connect via the internet and interconnect with each other with the least amount of human support. The main goal of IoT devices is to construct an enhanced world for humans. Within the enhanced world, an object will become acquainted with the user's likes, needs and wants and perform accordingly without explicit instruction provided by humans. Figure 1 displays a summarised definition and purpose of the IoT. As stated by Rowland et al. (2015), different interaction methods are available for end users to interact with smart devices and an important element to consider is the *interuseability* of these devices. Interuseability can be defined as a “distributed user experience across multiple devices”. The focus should not only be on an individual device's user interface (UI) but also on how the user interface (UI) aligns with other connected devices.

Figure 1: Internet of Things



Source: (Perera et al., 2013)

According to Balta-Ozkan et al. (2013: 364), a smart home can be defined as:

> [A] smart home is a residence equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the needs of its inhabitants. (Balta-Ozkan et al.)

Different type of IoT application exists within the industry e.g. logistics, retail, traffic, and smart cities etc. (Čolaković & Hadžialić, 2018) but as part of this research paper, the focus is on the retail application which includes smart home devices. As stated by Risteska Stojkoska & Trivodaliev (2017), three different type of home appliances exists within the Demand Side Management (DSM). A Demand Side Management (DSM) is a system that can enables the management and controlling of production/consumption of energy at a consumer level. The home appliances categories include: non-flexible, dual nature and flexible appliances. Non-flexible appliances include appliances that cannot be controlled by a central system e.g. Personal Computer (PC), Television (TV) and hair dryer etc. Dual nature home appliances are appliances that can be flexible or non-flexible on the user demand or needs e.g. dish washer or washing machine etc. A flexible appliance are appliances that can be automatically controlled by a system, an example is air-conditioning.

As mentioned by Munirathinam (2020), Within a smart home environment, different type of devices and systems can be installed and integrated with each other to deliver a service to the end user. A smart Television (TV) can be connected to the internet to retrieve content through on-demand video services like Netflix. Smart lights can be installed and controlled remotely with the internet connectivity capabilities. Philips Hue which is a type of smart lights has the capability to detect user movement/sunlight and adjust the lighting accordingly. Smart locks uses the wireless protocols to lock/unlock the doors based on cryptographic key, biometric and facial recognition technology(Celestine, 2020).

In a study conducted by Marikyan et al. (2019), four main user benefits of smart home devices are highlighted. These benefits are financial, health-related, environmental and psychological well-being. Smart home devices can be gradually introduced into the home space, converting a traditional house into a smart house (Marikyan et al., 2019). In a research conducted by Wilson et al., (2017), the benefits of using the smart home device were discussed. Several participants indicated that with the introduction of smart home technology, they were able to better manage their energy consumption by effectively monitoring and controlling the energy usage as well as identifying areas where additional money can be saved. Participants also highlighted that they enjoy the convenience and improved health features that smart home technology provides to them. An example of an energy consumption feature is preheating the house before the residents arrive. The intention of the United Kingdom (UK) government of utilising smart home technology to manage the energy grid was also discussed in the paper (Wilson et al., 2017).

2.4 USER PERCEPTION AND MOTIVATION

Individuals have different motivations for purchasing and installing a smart home device. In a study conducted by Woo and Lim (2015), user motivation for setting up a *do-it-yourself* (DIY) smart home is to solve problems that exist within their daily routines. The smart home usage cycle was designed to identify and solve the current problem that end users face within their home environments. The management of energy consumption in households has been identified as a motivation for purchasing smart home devices (Jensen et al., 2018). The end user can use energy monitor reports to divide the cost of electricity among household members and provide an incentive to children for reducing their consumption of energy (Coughlan et al., 2012). According to end users, the voice assistant (VA) has become a favourite companion and they have built a relationship with the technology. The end user uses the voice assistant (VA) for accessing information, companionship and entertainment services (Ammari et al., 2019).

As mentioned by Ammari et al. (2019), end users are installing smart devices because they want to reside in a modern household with advanced technology. While they perceive the benefits of using an IoT device, in a study conducted by Jakobi et al. (2018), end users had concerns about the manageability and unreliable behaviour of smart devices. Installing smart home devices in a personal space might assist parents in monitoring household activities but past research highlights that surveillance activity can create tension in parent–child relationships. An example is parents constantly monitoring sick children through a smart device, which could lead to an invasion of the child's privacy (Coughlan et al., 2012). As stated by Balta-Ozkan et al. (2013), consumers in the United States (US) consumers had concerns related to smart meter technologies. These concerns are related to the violation of their privacy, cost increases and consumers not having sufficient control over their energy consumption. For certain households, convenience and comfort were more important factors than financial savings for implementing the smart home technology inside their personal spaces (Balta-Ozkan et al. 2013).

2.4.1 Trust Factor

As mentioned by Nazari Shirehjini and Semsar (2017), user trust in an automated system is a crucial factor that determines the success of the technology implementation. Building the trust factor is an ongoing process and end users need to comprehend the current state of the system for them to predict the system's behaviour. Therefore, a sufficient representation of the system must be provided to the user to assist them in constructing the mental model of the technology as well as increase their trust. As highlighted by Nuamah and Seong (2017), managing user trust is an essential component in accepting smart technology. These are two elements of trust which should be considered by IoT device designers from user perspective and the interaction between different entities. In a systematic literature review conducted by Yan et al. (2014), the lack of research conducted on Human–Computer Trust Interaction (HCTI) is highlighted. The goal of Human-computer trust interaction (HCTI) is to provide usable and trustworthy interaction with the smart device to the end user. Human–Computer trust interaction (HCTI) aims for a user to have confidence in the technology and he/she is willing to act on the recommendations and actions provided by an artificial intelligence-(AI) enabled system. The presentation and consistency of the generated information by the device can lead to an increased trust factor.

In a study conducted by Jakobi et al. (2018), participants raised concerns about the reliability of smart devices. After the initial configuration of smart home devices, users were not comfortable with the technology and its performance. Users feared that the system might behave unpredictably and they were not certain if they had done the initial configuration correctly. The users reviewed the home logs to ensure that the smart device was operating as intended. The lack of proper feedback channels provided by the smart device manufacturer is highlighted as problematic for end users (Jakobi et al., 2018).

As suggested by Coughlan et al. (2012), appropriate design of the data access and legal terms can assist in enabling the trust factor in the end user. Per existing implementation, a software product requires the end user to review and consent to extensive terms and conditions and agree to a list of rules that might not be clearly articulated for the end user. The ongoing software updates might result in a change to the terms and conditions that were accepted by the end user in the initial set-up of the service. Past literature has also highlighted that end users are uneasy about accepting terms that include capturing data from within their home environments (Coughlan et al., 2012). As stated by Edu et al.(2021), there are existing privacy and security risks related to the usage of a smart personal assistant (SPA) but if users were made aware of these risks and are educated on what mechanisms mitigate the risk, the user experience of the smart personal assistant (SPA) could be enhanced. In a few cases, end users are not utilising all the functionality provided by the smart personal assistant (SPA) because they do not fully trust the technology and are unaware of the mechanisms that they can use to protect themselves. Another element that impacts the trust factor is the data collected by the device itself. Source data could be inaccurate and result in a veracity challenge if a sensor does not function as expected (Bansal et al., 2020).

2.4.2 IoT Device Management

IoT device management is an important factor for successfully deploying the technology (Čolaković & Hadžialić, 2018). IoT device management challenges includes device control, device configuration and device monitoring. These management challenges can occur due to the number of IoT devices that are deployed on the network, the complexity of the technology, device heterogeneity and the traffic requirement. IoT products should have self-configuration capabilities of which an example is a device switching off automatically when there is no user activity detected (Čolaković & Hadžialić, 2018). As highlighted by Jakobi et al. (2018), managing an IoT device is challenging for end users. In a household context where space is shared with more than one person, it is difficult to manage IoT devices because each individual in a household has different needs that they expect to be fulfilled by a device. As stated by Woo and Lim (2015), smart home device implementation should focus on efficiency as well as the emotional factor. An example of the emotional factor is the impact of smart device rules on other household members. As mentioned by Corno et al. (2017), end users with or without programming skills are seeking to customise the behaviour of the IoT devices towards fulfilling their personal needs. Another device management challenge is the interoperability between different smart device types and the device manufacturer. This challenge can impact the end user's ability to successfully customise their smart device services.

End-user programming (EUD) is a technique that aims to support end users who are not professional developers to learn special programming skills which can assist them in managing their software and devices. These special programming skills can include web authoring tools, spreadsheets or a professional coding language like Java. It provides the end user with the required knowledge to manage their smart devices without being dependent on a technical expert (Barricelli et al., 2019). As highlighted by Woo and Lim (2015), the goal of end-user programming (EUD) for smart home devices is to make different interfaces available to end users that can assist them with creating and managing the smart home environment. In a home context, end-user programming (EUD) might not always be the ideal option for smart homes as it might not align efficiently with the user's daily routine. End-user programming (EUD) provides the capability to control smart devices but the end user requires control over the device as well as their lives (Davidoff et al., 2006). Smart home devices (e.g., sensors or actuators) should be accompanied by efficient methods of physical integration within the home space to avoid disrupting the existing household interior (Woo & Lim, 2015).

In a study conducted by Jensen et al. (2018), the energy consumption factor of smart home devices was discussed. To serve the required household needs, smart devices like Alexa are used to manage their smart home environment. These devices are constantly switched on and consume electricity to operate. Managing the house's doors remotely was highlighted as a time-saving feature since the end user does need to be physically at home to open the door. The Hue Bridge system was also used by the study's participants to allow their smart home devices to connect and communicate with each other. However, these hubs running in the background are constantly consuming energy that might power other devices, which creates further energy demands to cool down the server (Jensen et al., 2018).

2.5 IOT DEVICE PRIVACY AND SECURITY

As highlighted by Zheng et al. (2018), several research studies have been conducted around user perception on collected device data and the privacy of the IoT (Apthorpe et al., 2017; Conti et al., 2016; Molina-Markham et al., 2010; Obermaier & Hutle, 2016). Those studies have highlighted that privacy preferences for an IoT device is context-dependent and diverse. When it comes to the risk associated with device privacy, end users weigh the device privacy risk against the benefits produced by the IoT device. In a research study conducted by Ammari et al. (2019), end users raised the issue that the privacy controls provided by the virtual assistant devices were inconvenient and difficult to comprehend. IoT devices like virtual assistants that are always switched on and listening silently in the background pose additional challenges for managing users' privacy. End users are uneasy regarding the data being collected by IoT devices in their personal spaces and sharing generated data with third parties. As mentioned by Oulasvirta et al. (2012), Some users are changing how they behave by avoiding places that have sensors/microphones or avoiding walking around naked in their homes to prevent privacy violations since IoT devices are integrated with their households. As stated by Edu et al. (2021), several security issues with the smart personal assistant had been reported. An example included in the study was Amazon’s Alexa device where personal conversations had been recorded and were sent to end user contacts without the end user of the device being aware of it.

As mentioned by Koreshoff et al. (2013), past studies have focused on the technical privacy factors of IoT devices which include infrastructure and other technical components (Y.K. Chen, 2012; Romana et al., 2013). There is an opportunity for the Human-Computer Interaction (HCI) community to review and acknowledge user privacy concerns while building the IoT device. An article written by Chow (2017) highlights that one of the key privacy concerns with IoT devices is the user being unaware of data collection due to the ubiquitous nature of the IoT technology. The article also provides a suggestion for introducing privacy notifications when a user's data is being collected in a particular space (e.g., homes or shopping malls). Data collection awareness is a vital component that needs to be considered when designing an IoT product. The privacy-related notification can be integrated into smart home systems.

As stated by Ndubuaku and Okereafor (2015), end users of IoT devices need to become educated on the privacy and security elements of the devices. That includes details on how to access IoT devices and how to manage different permissions related to the IoT devices. IoT devices are also vulnerable to information theft and therefore, the required security controls must be implemented on an infrastructure level to protect end-user data. Perera et al., (2013) also highlight the need for handling the privacy and security element of the IoT on a different level. The focus point of that study was the hardware that stores the device data. Since personal data might be collected by IoT devices, there is a need to support end users in managing access to their personal information and collecting usage data anonymously (Perera et al., 2013). As highlighted by Coughlan et al. (2012), a household is considered a personal space and factors such as privacy, control and ownership must be carefully considered. Even if the collected device data may not be attached to an individual, it can still reveal personal information.

The South African government has established laws that focus on the protection of an individual's personal data namely the Protection of Personal Information Act (PoPi or POPIA). According to the Popi act, consent can be defined as "'consent' means any voluntary, specific and informed expression of will in terms of which permission is given for the processing of personal information" (*Protection of Personal Information Act*, 2013: 12). If an organisation is dealing with any type of customer personal data, they are required to abide by the law and implement all the required measures to protect their customers' personal information.

Urquhart and Rodden (2017) discuss the problems related to obtaining consent via the form contract in their research. The 'form contracts' approach is considered a dominant approach for collecting consent from the end user. The contract includes two elements, i.e., the choice that is provided to the end user to either accept or decline the contract and a notice where the details related to the company privacy policy are included. The concerns are related to the clauses that are included in the terms and conditions section which are not favourable to end users. The end user is not likely to read the terms and conditions and therefore, they are not aware of what they are consenting to when they make use of a service. Thus, if they would like to make use of the service, an end user must provide their consent. The consent-obtaining process for the IoT is still a challenge where the end user's interaction with the device might be ubiquitous and ambient. The trajectories framework is suggested as a useful tool for gathering consent related to the IoT device from the end user (Urquhart & Rodden, 2017).

Device designers should ensure that the terms related to the data processing of usage data are apparent to the end user. An example of this is the Hypertext Transfer Protocol Secure (HTTPS) protocol where ‘S’ and the padlock icon signify that the webpage is secured for processing personal details (Schraefel et al., 2017).

2.6 IOT DEVICE DATA

When it comes to the enablement of the IoT devices, Big Data is one of the key enablers of the technology. One of the reasons for the slow adoption of IoT devices is the lack of big data management. For smart devices to fully perform and reach their potential, reliable and accurate data is required to assist in real-time decision-making and device performance (Bansal et al., 2020).

2.6.1 Data Collection

As highlighted by Ndubuaku and Okereafor (2015), IoT will cease to exist if there is no data available to 'pump' the technology. Data is described as being the fuel of the IoT industry and it is imperative that is managed to harness its true benefits for businesses and consumers. Sensors are used to collect IoT device data and the number of installed sensors are predicted to increase in the foreseen future (Perera et al., 2013). In a recent studies conducted in 2022 by Carrera-Rivera et al. (2022), the context life cycle described by Perera is discussed and the following four steps were defined: context acquisition, context reasoning, context dissemination and context monitoring. The cycle deals with collecting, processing and presenting context smart device data to the end user. In a study conducted by Zheng et al. (2018), end users had different opinions regarding IoT data collection. Depending on the data consuming parties (e.g., internet service providers (ISPs), the government or advertisers) and collection type (e.g., anonymous or disclosing personal detail) end users had different concerns and opinions on sharing their data. The majority of the participants in the study were comfortable with sharing data with the device manufacturers but disliked the idea of internet service providers (ISP) and the government having access to their smart home data. Another study conducted by Ammari et al. (2019) discovered that consumers were not comfortable with smart home IoT devices collecting their data and sharing it with other third-party providers. In another research study conducted by Bhatnagar and Kumra (2020), end users sharing their IoT usage data was discussed. The types of users volunteered to share their data were early adopters and who were curious about how the data was being collected. End users need to comprehend how the IoT devices are collecting data in order to have adequate control over what data may be collected (Urquhart & Rodden, 2017).

In a few instances like with smart city monitoring tools, end users are unaware of the smart device being present in an area and therefore have a lack of control over what personal data is being collected. The end user is being treated as subjects for these smart devices rather than their users (Chow, 2017). When setting up IoT devices, consent is usually required for collecting device usage data but the issue emerges when end users are unaware of what data is being collected due to the time required to read through the terms and conditions. Even if the user had read and accepted the Terms and Conditions (T & Cs), they might not have fully understood what they have agreed to. Consent is not a once-off item that needs to be agreed to by the end user, but rather is a constant loop where the terms and conditions should be presented in such a way that any type of user is able to comprehend fully how data is flowing between different systems and how it is being used (Schraefel et al., 2017)

2.6.2 Data Processing

Traditional systems or solutions focused on collecting and processing data from a limited number of hardware and software sources but this approach is not feasible in an IoT space as thousands of sensors are connected to the internet and it is not viable to process all the data collected by the sensors. To resolve the processing data issue, a context awareness feature was introduced to decide which data is required to be processed. Context-aware computing has previously been implemented successfully in the pervasive and mobile paradigms and it can be successful in the IoT paradigm as well. It enables devices to store the related context detail that is linked to the sensor data. By enabling that function, it can simplify the interpretation process in the devices(Perera et al., 2013).

As discussed by Čolaković and Hadžialić (2018), several data mining tools are being used to identify patterns in Big Data. These data mining tools can be machine learning models or Artificial Intelligence (AI). The tools can then be used to derive valuable information for the end user. The big data generated by IoT devices can also be processed using a hybrid analysis method that includes the use of machine learning and deep learning techniques. The hybrid analysis model can assist with executing the advanced analysis to enable proactive monitoring or predictive analysis.

Data processing suffers from several challenges that include delivery of the results in real time from smart devices, extracting meaningful information from real-time devices which require advanced technique models; furthermore, the data being supplied by various sources can result in incomplete data (Bansal et al., 2020). The main challenge and opportunity related to the IoT is comprehending the collected data. The *Smart IoT* is described by the research community as an ecosystem that enables the comprehension of collected IoT big data. Smart IoT enables intelligent systems that provide real-time decision-making functionalities (Sheth, 2016).

2.6.3 Data Presentation

IoT devices use sensors to collect device usage-related raw data but for it to be beneficial to the end user, the raw data needs to be converted into task-relevant and meaningful information. The generated information must then be presented in a manner that a human can function with. The presentation type used for information is crucial as that determines how an individual can identify patterns from a big set of data (Nuamah & Seong, 2017).

Because real-time IoT device data is available in more than one data format, it can be difficult to present in summarised interactive visuals. Visualisation of IoT data can also be a challenge due to nonstop analysis loops and the high dimensionality of the collected data (Bansal et al., 2020). As mentioned by Ammari et al. (2019), one of the presentation methods that could be utilised for displaying terms and conditions of the system usage is an actual visual demonstration of the collected usage data rather than displaying the usage data in a written format to end users.

IBM provides the following definition for data visualisation (IBM, 2021):

> Data visualisation is the representation of data through use of common graphics, such as charts, plots, infographics, and even animations. These visual displays of information communicate complex data relationships and data-driven insights in a way that is easy to understand. (IBM,2021)

By using visualisation as the information presentation method, it assists humans with generating insight through their cognitive and perceptual abilities. (Robertson et al., 2009).

As highlighted by Tory and Moller (2004), simply selecting the relevant graphic representation method is not sufficient for supporting an end-user task. End users play a very crucial role in the visualisation process. Since the artefacts are designed to benefit the end user of the device, it is imperative to focus on an individual who would manipulate and view the data. The usefulness of visualisation is dependent on the end user's goals, cognition and perception. The factors that impact a viewer's perception of a visualisation item are the user's experience, colour, light, visual acuity, lighting, culture, etc. Previous research has also focused on how 2D and 3D graphic visualisation can be used to display information to end users (Čolaković & Hadžialić, 2018).

As noted, by Koreshoff et al. (2013), cell-phone notifications were the most popular method of communicating communicate smart device data to end users. In another research study, historic and real-time data consumption were visualised on a smart home system to provide feedback on smart home devices' energy consumption (Jensen et al., 2018).

2.7 SEMANTIC COMPUTING

In a book written by Sheu et al. (2011: 1) the authors provide the definition for semantic computing below:

> We define semantic computing as a field that addresses the derivation and matching of user intentions to help retrieve, manage, manipulate, or even create the content, where "content" may be anything including video, audio, test, process, service, hardware, network, community and so on. (Sheu et al., 2011: 1)

Semantic computing can be utilised in various fields. These fields include (but are not limited to) data and knowledge generation, natural language processing and pattern recognition (Sheu, 2008).

Semantic computing can be summarised as generating meaning from data that is collected from different resources. IoT devices generate data that can be structured or unstructured. The cause-and-effect challenges of the IoT data processing noted by Bansal et al. (2020) include the need for effective semantic processing. The challenge is related to managing of the sensor vocabularies and ontologies. Semantic computing can assist with the heterogeneity issue related to IoT data. Heterogeneity can be defined as collecting data from various sources such as sensors and devices. It can also assist with deriving meaning from collected IoT device data (Sheth, 2016).

Three different IoT paradigms have been identified by Atzori et al. (2010) in their study: semantic-oriented, things-oriented and internet-oriented. The semantic-oriented paradigm relates to the technology stack that transforms IoT data to generate information that is useful to the end-user of a smart device. Atzori et al. (2010) argue that the semantic-oriented paradigm uses different modelling solutions to make sense of the collected data (Nuamah & Seong, 2017). Semiotic engineering is the study of signs and the theory can be used to determine the quality of a system concerning the system usage. According to the semiotic engineering theory, a software product should consider the following factors in the development phase: end-user understanding of system behaviour, the target audience for the software product and the main purpose of the system that describes the possible interaction with a system (Ferrari & Aquino Junior, 2016).

One of the use cases where semantic computing has been integrated within the IoT field is the *EUPoint* software tool. This tool can be used by the end-user with limited programming knowledge to effectively manage several IoT devices by defining either a few or high-level rules. The tool uses semantic reasoning to simplify the definition of rules that trigger various IoT devices (Corno et al., 2017).

2.8 COGNITIVE COMPUTING

Cognitive computing is a system that aims to generate valuable insights from a large set of data using experience and reasoning. The purpose of cognitive computing is to simulate the processing of the cognitive component of the human brain and assist in solving complex problems and tasks (Sheth, 2016). It does not depend on being explicitly programmed, but rather learning from various interactions and experiences with humans and their respective environments (*Cognitive Computing*, 2017). It aims to resolve the issue of uncertainty and surprises in the current biological system (M. Chen et al., 2018).

In their research study, Coccoli et al. (2016) state that cognitive computing will have a beneficial impact on the IoT due to its ability to process different types of data and provide real-time insight to the end-user. It facilitates an innovative way of interaction between systems and humans. The real value of cognitive computing resides with its integration with the IoT (Holtel, 2014).

The cognitive system improves its learning by performing a set of tasks repeatedly. The driving tools behind cognitive computing are natural language processing, data mining and pattern recognition. The term Cognitive IoT describes the relationship between the IoT and cognitive computing (Sheth, 2016). To fully understand the different needs of a human being, it is imperative to strengthen the cognition component of a machine via the use of cognitive computing. This technology enables machines to comprehend the real world from a human being's intellectual perspective (Chen et al., 2018).

Vermesan and Bacquet (2017) identified and explained a list of challenges in relation to the IoT and cognitive capabilities. Some of these challenges are:

- Model algorithm transparency is required from the cognitive systems to understand why certain automated decisions were actioned/suggested. Due to the complexity of the model, at times, the model's developers cannot fully comprehend the model itself. Accountability needs to be taken into account if any damage occurs due to the autonomous systems e.g., accidents occurring because of smart cars.

- In the case of fully automated IoT applications, there is very heavy reliance on the quality data that is being used in the decision-making model. Data generated by IoT applications needs to be accurate and reliable to manage the established confidence in the technology.
- Security factors are crucial in IoT technology. Cognitive capabilities (e.g., machine learning and artificial intelligence) are responsible for their learning via interaction with their current surroundings. They should also have the capability to deal with harmful and unpredictable events e.g., hackers infecting the training data of the model.

2.9 DESIGN CHALLENGES OF IOT DEVICES

HCI visions have been established by several HCI practitioners who describe the design challenges related to smart home devices. These visions are 'calm' computing, a sustainable smart home and engaging experiences. The idea related to a sustainable smart home focuses on the energy consumption of the smart devices in a household. HCI practitioners emphasise that when designing smart devices, the aim should be to reduce energy consumption (Jensen et al., 2018). The calm computing vision by Weiser and Brown (1997), highlights the embedding of ubiquitous computing in the user’s daily life. The focus of the research was the challenge of designing smart devices that seamlessly integrate with human life and to provide the end user with adequate control over the technology.

As highlighted by Urquhart and Rodden (2017), HCI has several design challenges with regulating the domestic IoT. A household cannot become a smart home instantly, it takes time before a house can be labelled as smart and how technology products are integrated into a household varies as the domestic space is constantly evolving. A study conducted by Woo and Lim (2015) found that the usage of do-it-yourself (DIY) smart home products were meant to resolve issues in people's daily routine. Smart devices must be designed in a way that they are embedded into a household routine.

The IoT framework for the smart home designed by Risteska Stojkoska and Trivodaliev (2017) explains the importance of an effective user interface level that aggregates raw smart device data into simplified visualisation that a user can comprehend. This data is delivered to the end user through various methods, e.g., notifications or controllers for smart devices. The designs of these visualisations should be evaluated against the Quality of Experience (QoE) metrics to ensure that the design meets the user requirements. As defined by Fiedler et al. (2010), Quality of Experience (QoE) can be defined as a concept that focuses on the end user's expectations and perceptions of a technology product. It takes into account the technical as well as the non-technical parameters of the product. As stated by Goyal (2015), IoT device designers must consider the learning curve while building the device. Many connected devices are not made with interfaces that meet the available user experience (UX) standards. The recommendation is to build the device with frequently used user experience (UX) designs (e.g., touch).

When it comes to smart home device building, a prominent question has been brought up by Nazari Shirehjini and Semsar (2017) on how we manage these devices that have limited to no user interface on the actual device. How does a user effectively interact with these devices in a smart environment? With the increasing number of connected smart devices (Urquhart & Rodden, 2017), the HCI designer should consider these factors while building these devices.

2.10 SOCIAL THEORIES

As part of the literature review, the following theories were described: *cognitive dissonance theory, activity theory and cognitive load theory*. The social theories were discussed in this section to provide insights on how the social theories have been applied on past HCI research. As part of this research study, Cognitive load theory was selected as lens to analyse the collected data. The reason for selecting cognitive load theory for analysing the data was because they align with the research problem and assisted in understanding the adoption and individual perception of an IoT device.

Cognitive dissonance theory is a type of theory that can be utilised to describe a person's behaviour when there is a gap between a person's perceptions when purchasing a product vs when the product is utilised. This theory links to the emotions that are generated when a certain product does not meet the required expectations and it leads to having more than one contradictory cognition. Dissonance is, therefore, created when negative emotions are linked to the product's performance (Park et al., 2015). Cognitive load theory has been previously explored in the Ubiquitous Computing (Ubicomp) and Human Computer Interaction (HCI) communities to identify how innovation technologies can be utilised to encourage users to changes their behaviour or perceptions. An example is when the user alter their water usage behaviour when they were presented with their water usage data(Maimone et al., 2014).

An individual can take the following three measures to minimise the dissonance: change his/her attitude towards the product, change his/her behaviour or seek information. The attitude change measure focuses on changing the initial expectation for a product and its performance. The individual has one constant state of mind for the product and rejects any alternative experience. The constant of information measure focuses on an individual motivating their decision for product purchase by seeking information from advertisements or 'word-of-mouth'. The behavioural change measure focuses on behavioural changes that cause dissonance (Marikyan et al., 2020). As stated by Cheng and Chen (2022), cognitive dissonance can also be eliminated by the following two elements, namely behavioural or cognitive strategies. Cognitive strategies focus on the psychological changes that are linked to an individual’s cognitive resources. An example of a cognitive strategy is when a consumer previously had cognitive dissonance and negative feelings for a product/service develops a positive attitude based on the positive feedback received from a salesman on the product/service. Behavioural strategies focus on an individual who has cognitive dissonance altering their current behaviour to decrease the cognitive dissonance. An example of a behavioural strategy is when a consumer who favours product receives negative reviews on the product and then changes their behaviour and feelings toward the product.

Nardi (1995), defines activity theory “a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, both individual and social levels interlinked at the same time”. Activity theory has the following three principles: artefacts and mediation, history and development, and activity as a unit of analysis. The artefacts and mediation principles focus on the activities of the artefacts and the mediation feature it provides. Activity artefacts can be signs, machines, laws or instruments, etc. The relationship between these artefacts is not direct, but rather mediated. The history and development principles focus on the historical aspect of an activity. Activities are constantly developing and changing and it is crucial to understand the historical development of the activity that is under analysis. The activity as a unit of analysis principle focuses on the required context to analyse an activity as a unit (Nardi, 1995). Activity theory was introduced to the world of HCI around the 1980s and is widely used in the HCI field for various purposes (Clemmensen et al., 2016). In late 1900s, crucial development took place in the implementation of the theory with regard to people's usage of technology. Researchers have noted that activity theory has assisted them with obtaining a detailed understanding of the technology and the impact it has on individuals. Activity theory has also been combined with other extensive theories (Kaptelinin & Nardi, 2018).

Over the years, activity theory has been used in three different ways; namely, providing a conceptual tool that can be used for evaluating and designing to the researcher, enhancing existing HCI concepts and lastly, it has been used as a theoretical framework in empirical research studies. Activity theory is not a typical theory that allows the researcher to 'plug' in the required collected data and assist with achieving a result, rather it assists the researcher in asking the correct questions during the data collection phases. This theory assists novice researchers in solving complex problems. It helps researchers comprehend how humans interact with computing devices. The main basis of the theory is that people interact with the world via computers (Kaptelinin & Nardi, 2012). Activity theory has previously been used for IoT use cases in a study conducted by Kim et al. (2015), where the basics of activity theory (subject, tool and object) are used to identify different interactions between humans and IoT devices. As stated by Blayone (2019), based on the evolution of the model, activity theory consists of the following six elements of human activity: subject, tools and signs, rules, community, division of labour and the object. To link the theory with digital products, additional dynamics were generated based on Leontiev and Vygotsky's previous work(Leontiev, 2006).

Cognitive load theory is a type of theory that is concerned with the method that is utilised to consume cognitive resources during the problem-solving and learning stages (Chandler

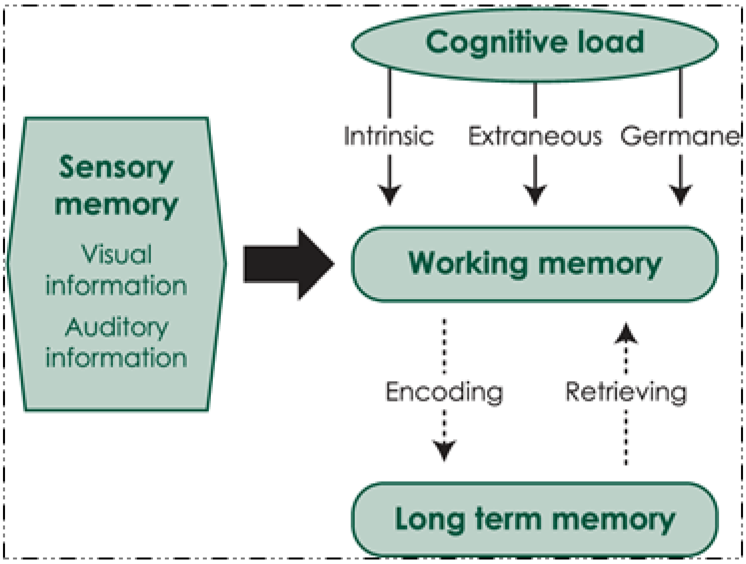
& Sweller, 1991). This theory is built upon the concept of restricted working memory size and huge long-term memory size. Hollender et al. (2010) highlight the link between the HCI concept and cognitive load theory. From a useability and user experience point of view, one of the goals is to reduce the cognitive load on a user by simplifying the software design. The main goal of the theory is to put less cognitive load on the working memory of a learner because it is limited.

As stated by Oviatt (2006), cognitive load has been used as a global term to describe the mental resources a human has available for finishing a task and resolving a problem. The theory focuses on creating interfaces that can reduce the cognitive load placed on a user so they can use the remaining cognitive resource to focus on the main task. The following cognitive load theory principles have been applied to the design of software: the redundancy principle and the spilt-attention principle. The redundancy principle focuses on preventing information reiteration on the screens. The split-attention principle focuses on reducing the information load on a user by building software that does not require users to remember large amounts of information to complete a task. The information pieces should be presented in closed structural proximity (Hollender et al., 2010).

As described by Ayres & Gog (2009), Cognitive load theory is centred around a user memory system. Cognitive load theory describe the correlation between long-term and short-term memory. The theory assumes that the working-memory is limited for storing information and long-term memory allows the user to store a vast amount of information. The focus of the theory is to reduce memory load on the working-memory which results in effective learning of new concepts or information. As stated by Feinberg and Murphy (2000), they are three types of memory: long-term memory, working memory and sensory memory. Long-term memory is where we permanently store our knowledge and skills and has no limit to its capacity. Working memory, on the other hand, is limited and that's where human learning takes place. Sensory memory refers to the process of using our senses like seeing or hearing to process an activity. An increase in extraneous cognitive load can negatively impact the human learning process.

Cognitive load theory includes three types of loads: intrinsic, extraneous and germaine. Intrinsic cognitive load refers to the set of information that needs to be learnt by a user and how the information should be presented to maximise the learning process. Extraneous cognitive load refers to the increase in working memory due to unclear or unnecessary instructions provided to the user. Germaine cognitive load reviews a learner's characteristics and the impact it has on the learning process. Germaine cognitive load theory may result in an effective learning process. (Orru & Longo, 2019; Sweller, 2010). Figure 2 depicts the visual representation of cognitive load theory (Chinnappan & Chandler, 2010).

Figure 2: Cognitive Load Theory



Source: (Chinnappan & Chandler, 2010)

2.11 CONCLUSION

Chapter 2 dealt with the literature review which included an analysis of the existing body of knowledge related to HCI principles and its impact on IoT devices. Based on the analysis of the existing body of knowledge, the following themes were identified: HCI design principles and rules, IoT purpose, user perception and motivation, trust factor, IoT device management, IoT device privacy and security, IoT device data, semantic computing, cognitive computing and the design challenges of IoT devices and Human-Computer Interaction theory.

The literature review focused on the end-to-end user journey for using an IoT device. It focused on understanding the reasons why an end user purchases a smart device and the challenges that the user faces while managing the smart device. Privacy and security were a common concern raised by the participants in previous studies. Existing Human-Computer Interaction (HCI) principles, rules and theory were reviewed as part of the literature review. The impact of IoT device data collection, processing and management on users' emotions was also discussed in detail. To fully harness the benefits of smart devices, data needs to be captured and processed by device manufacturers. The importance of presenting the collected usage data in a simplified manner was highlighted in previous research studies. Past researchers suggested semantic and cognitive computing to process IoT device data and generate useful information that assists end users in their daily activities.

As part of the Human-Computer Interaction theory section, three theories were reviewed and discussed: cognitive dissonance theory, cognitive load theory and activity theory. The integration between the above-mentioned theories and HCI was highlighted in Chapter 2.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

Research methodology is the process of how a researcher addresses the research questions. This process includes various methods and strategies that are adopted by the research study to answer the main research question (Oates, 2006). It is a general approach taken by researchers to complete a research study (Brent & Leedy, 2015). In this study, the research methodology was used to answer the primary research question: "*What are the principles of Human–Computer Interface in Internet of Things (IoT) devices?"*

The purpose of this chapter is to elaborate and discuss the research design selected for this study in detail, the sampling method selected and utilised, how the source data was collected, what tools and methods were used to analyse the collected data and explain how the research study was conducted ethically.

3.2 RESEARCH DESIGN

A research paradigm refers to an individual's way of thinking. Three research paradigms within in the information system (IS) discipline are available to researchers when conducting a research study. These paradigms are interpretivism, positivism and critical research (Oates, 2006). Researchers who select the positivism paradigm as a method believe that knowledge can only be acquired through experiments or observation. This paradigm utilises a scientific method to generate new knowledge (Rahi, 2017). Researchers who select the critical research paradigm as a method believe that society is created by the people who live in it but the power structures and conflicts have an impact on an individual's experience and how they perceive the world (Oates, 2006).

The research paradigm selected for this study is interpretivism as defined by Oates (2006:292):

> Interpretive research in IS and computing is concerned with understanding the social context of an information system: the social

> processes by which it is developed and construed by people and through which it influences and is influenced by its social setting. (Oates, 2006:292)

Interpretivist believe that there is no single truth or reality. Reality is therefore shaped by individuals' social interactions within a group. The real world is perceived differently by different cultures or groups of people. Interpretivists aim to comprehend a group of people in a real-world setting rather than in an artificial world (Oates, 2006). Interpretivism is a paradigm that is an adequate choice for this research as it allows the researcher to understand how a person or group perceives their world and per the research question, to comprehend and identify the perceptions of end users as related to IoT devices. The perception might differ from person-to-person.

As related to the chosen paradigm, a qualitative research approach was taken for conducting the research. A qualitative research approach can be defined as understanding or interpreting an existing phenomenon (Brent & Leedy, 2015). It is classified as a "multi-method approach that includes gathering and usage of a combination of empirical materials and therefore it can be classified as an 'interpretive science'" (Aspers & Corte, 2019). As stated by Clemmensen et al. (2016), the focus of qualitative research is more on the abilities of a particular technology and how an individual perceives, feels and utilises that technology in their daily lives. Oates (2006), highlights that HCI researchers lean more towards the qualitative research approach for obtaining research results that fulfil the needs of the HCI field. Table 3 describes the advantages and disadvantages of conducting qualitative research (Johnson & Onwuegbuzie, 2004):

Table 3: Qualitative Research

Advantages	Disadvantages
It is effective for studying a small number of cases in detail.	The findings/results/knowledge that are generated in the study may not be able to be generalised to other situations or individuals.
It has the potential of explaining an identified or an existing phenomenon in detail as it will	It is challenging to make predictions in qualitative research.

be rooted in the local contexts.	
The raw data is mostly collected in a naturalistic situation.	It is very challenging to examine theories and hypotheses.
The researcher can use the grounded theory to inductively construct a descriptive theory about a specific phenomenon.	It takes a great amount of time to collect raw data for conducting data analysis
This research approach is effective in unfolding a complicated phenomenon.	

The motivation for selecting a qualitative research approach for this study was because it assisted in comprehending the identified phenomena in detail. This approach also allowed the researcher to select a small sample to collect and analyse data. The purpose of this research is not to generalise the results on a sample, but rather to understand the identified phenomena in depth.

The research strategy selected for this study is the case study approach. A case study strategy tends to focus on the occurrence of a specific entity which needs to be investigated in detail (Oates, 2006). A case study strategy is more applicable for obtaining knowledge on a poorly understood area (Brent & Leedy, 2015). The motivation for selecting a case study strategy (Yin, 2014) is because a specific type of smart IoT device and location was used to investigate the implementation of the HCI principles on the IoT and how effective they are. The selected participants were part of a household and they were computer literate consumers who use smart home devices as well as an organisations employee who may have been involved in designing an IoT device.

Several Human-Computer Interaction (HCI) theoretical frameworks were described and compared in Chapter 2. Sweller's cognitive load theory (Sweller, 2011) was used as a lens through which to analyse the collected data. The reason for selecting cognitive load theory for analysing the data was because they align with the research problem and assisted in understanding the adoption and individual perception of an IoT device.

3.3 SAMPLING

Non-probabilistic sampling was chosen to select a sample and collect the required data to conclude a result for the study. Non-probabilistic sampling is a type of approach that is selected when the researcher is unsure about the sample of and event or people's representation and the researcher believes that each participant has unique characterises that cannot be generalised to other individuals in the rest of the population (Brent & Leedy, 2015). The goal of this study was not to generalise the finding to a large population, but rather to understand existing phenomena in depth. Therefore, a non-probabilistic sampling approach was appropriate for this study.

3.3.1 Target population

The main purpose of this study was to analyse and study the principles of HCI in an IoT device. Two types of participants were included as part of the study: smart home device consumers and organisational employees.

The following criteria were applied for selecting consumer participants as the sample population:

- The participants must have a smart home device installed within their house.
- The participants must reside in South Africa. There were no restrictions on the province.

The case study organisation where the data was collected is an organisation in the Information Communication Technology (ICT) sector. The case study organisation provides connectivity to IoT products. The organisation also offers a range of smart products to their consumers. The case study organisation is part of the telecommunication industry.

The following criteria were used for selecting certain organisations' employees as the sample population:

- The case study organisation employees' job titles may include designers, architects, system analysts, business analysts and management who may have been involved in building IoT devices.

3.3.2 Sampling method

Two sampling methods were selected to collect the required data and reduce the risk of non-probabilistic sampling. The first sampling method that was utilised for this study was self-selection sampling. Self-selection sampling allows a researcher to advertise their research intent and participants' criteria in an online forum, social media or any case study organisational channel that can be used to attract the required respondents and collect the data (Oates, 2006). The motivation for using self-selection as a sampling method was because the respondents would probably participate in the survey if he/she meets the required criteria for the study and the sample population for this research is unknown. As recommended by Vehovar et al. (2016) the non-probabilistic sample should be distributed as widely as possible by advertising the research request on different channels.

The second sample method selected for this study was quota sampling. Quota sampling allows the population to be subdivided into different groups (based on job level, generalist vs specialist, etc.) Nevertheless, the selection of the participants in these groups can be random (Brent & Leedy, 2015). By using this sampling method, the research sample was evenly distributed based on demographics and as Vehovar et al. (2016) state that quota sampling can be an effective strategy to form a non-probabilistic sampling technique. The implication of selecting a non-probabilistic sampling technique is that the research study results/findings do not provide a strong basis for generalising to an overall population and t have an impact on the credibility of the results generated (Oates, 2006).

3.3.3 Sample size

As the main goal of qualitative research is to obtain an in-depth understanding of existing phenomena rather than using the research finding to generalise a wider population, a sample size of 57 consumers who own a smart home device were requested to complete the questionnaire and ten case study employees were selected for the semi-structured interviews. As suggested by Oates (2006), a sample size of at least 30 participants can be defined as a sufficient sample size to produce reliable results.

3.4 DATA COLLECTION

A triangulation method was used to generate the required data for this study. A method triangulation can be defined as using two or more data collection methods to conduct a study (Oates, 2006). The following data collection methods were used to collect data: questionnaires and semi-structured interviews. The data collection methods and motivation for their selection are explained in detail below.

3.4.1 Questionnaire method

A questionnaire is a data collection method that can assist in obtaining general data from a wide population but can also be used for further data collection methods such as interviews (Oates, 2006). An internet-based questionnaire was used to collect IoT device usage experience data for this study and can be defined as a type of survey that leverages on the advantages of the internet and distributes surveys using emails or posting survey details in an online forum. The internet questionnaire was posted on various online forums and social media to gather sufficient data for this study.
Table 4 highlights the advantages and disadvantages of the questionnaire as a data collection method (Oates, 2006):

Table 4: Questionnaire

Advantages	Disadvantages
It can be an effective method to collect a vast amount of data in a short period.	Questionnaires do not provide a vast amount of detail for a research topic.
It is a cost-effective method for collecting data for the research study.	It only displays an association between identified variables.
It can be reused for a different set of sample sets.	Questionnaires are more fixated on measuring and counting sample data.
Questionnaires can be a good data collection method for people who struggle with communication skills.	It is very challenging to examine the truthfulness of participants' responses when using questionnaires.

The motivation for selecting a questionnaire as a data collection method for this research study was because it allows the researcher to collect data over a short period and is an effective method to collect IoT usage data from participants. It is a cost-effective manner and the questionnaire responses were collected electronically. The analysis of the collected data is simpler with this data collection method.

The questionnaire comprised of open-ended and close-ended questions. Seven questions were designed using the Likert scale, defined by Bertram (2007: 1):

> A psychometric response scale primarily used in questionnaires to obtain participant's preferences or degree of agreement with a statement or set of statements. Likert scales are a non-comparative scaling technique and are unidimensional (only measure a single trait) in nature. Respondents are asked to indicate their level of agreement with a given statement by way of an ordinal scale. (Bertram, 2007: 1)

The reason for selecting the Likert scale was due to its advantages such as it being simple to create, relatively easy for participants to review and complete, and it has a greater probability of producing dependable results (Bertram, 2007). Many researchers use the Likert scale to design questions for their surveys or questionnaires (Oates, 2006). Norman's design principles(D. A. Norman, 1998) and prior research studies that centred on Human-Computer Interaction and IoT was used as a guide for constructing the questionnaire. Appendix C includes the questionnaire template used to collect the required research data. A *Google* form was created to capture the responses for the questionnaire and a consent form was included in the introduction section. Questionnaire participants were required to provide their consent on the *Google* form. The questionnaire was divided into four themes, namely smart device information, smart device usage and maintenance, smart device data collection and smart device security.

3.4.2 Semi-structured Interviews

The second data collection method selected for this study was semi-structured interviews. Interviews are a type of conversation between several people. Interviews are usually planned and there is an identified agenda for initiating the conversation (Oates, 2006). The motivation for selecting interviews for data collection is because interviews can assist in obtaining high-quality qualitative information. It is an effective data generation method to collect data and analyse information on individuals' feelings, perspectives and motives on an event or thing (Brent & Leedy, 2015). The interviews were recorded using an audio recorder on a smartphone. This interview type allowed the participants to answer the question in an order that they are more comfortable with. It allowed the interviewees to provide more information on the raised issues. The following are the advantages and disadvantages of the interview as a data collection method (Oates, 2006).

Table 5: Semi-Structured Interview

Advantages	Disadvantages
An effective data collection method for a research topic that requires in-depth information.	Interviews are a very time-consuming data collection method.
Interviews require very little equipment to set up and conclude.	It can take a significant amount of time to perform analysis on unstructured data.
They are flexible concerning the questions that can be asked during an interview.	Interviews can be misleading in some cases as the researcher tends to focus on what an interviewee has experienced, which can be very different to the actual cause of a situation.
Interviews allow the researcher to confirm if the participant is the correct candidate for the research study.	Interviews can also be considered as not valid because they are recorded and the respondent may provide false information.
	They are not suitable for generalising to a wider population

The motivation for selecting a semi-structured interview as a data collection method was because it allows participants to answer the interview questions in a sequence they are comfortable with and if the researcher would like to ask additional questions as part of the interview, he/she would be able to do that with this data collection method. As the research focused on the identifying the design component that are considered when building an IoT device as well as understanding the current user experience of IoT, the semi-structured interview question were constructed to answer the research question described in chapter 1. Appendix D includes the semi-structured interview template that was used in the interview. The semi-structured interviews aimed to collect organisational employees' demographic data and their experience with using or building an IoT device. The semi-structured interview consisted of ten questions. The questions were divided into five sections: general understanding of the Human-Computer Interaction (HCI) and IoT concept, experience in building or using an IoT device, IoT design elements, IoT data collection and presentation, and IoT device security. The semi-structured interviews took an average of 30 minutes to conduct and the participants were required to sign a consent form to indicate voluntary participation.

3.4.3 Measurement

Two data collection methods were selected to answer the research question, a questionnaire and a semi-structured interview. In this section, different types of questionnaires and interview methods that are available are discussed. As defined by Acharya, (2010), a questionnaire can be defined as a "document containing questions and other types of items designed to solicit information appropriate to analysis". Three types of questionnaires are available to researchers: structured, quasi-structured and unstructured questionnaires. A structured questionnaire includes a list of questions that are pre-coded and are designed with a skipping pattern for sequential questions and is a popular quantitative data collection method. An unstructured questionnaire includes opinion-based and open-type questions. The unstructured questionnaire is a popular data collection method in the focus group. A quasi-structured questionnaire is a combination of structured and unstructured questionnaires and is a popular data collection method in social science research (Acharya, 2010). The quasi-structured questionnaire type was used to design the questionnaire for this study. The reason for selecting a quasi-structured questionnaire was because not all the questions in the questionnaire have identifiable possible alternatives and the study intended to gather and analyse the opinions and experiences of using a smart home device, which led to including three open-ended questions in the questionnaire.

As stated by Colosi (2006), two types of questions are used in questionnaires: open-ended questions and close-ended questions. Open-ended questions do not limit respondents on the answers they provide and are used in studies that focus on extracting individuals' opinions and experiences. A disadvantage of using open-ended questions is that it takes time to process all the responses which impacts the research's result delivery time. Despite these challenges, open-ended questions can be very useful in exploring and gathering responses that a researcher might not have predicted. A close-ended question limits an individual by having to select a response from a list of pre-defined responses. A respondent is unable to add further details to a close-ended question. Close-ended questions can be structured using the Likert scale, enforced choices and agree/disagree options. Close-ended questions ensure consistency in the responses provided by respondents and enable more efficient analysis of the collected data (Colosi, 2006). The questionnaire designed for this research study contained open- and close-ended questions.

As mentioned by Adhabi and Anozie (2017), there are three types of interviews that a researcher can use in qualitative research; structured interview, semi-structured interview, and unstructured interview. In a structured interview, the interviewer fully controls the interview process and the interviewee has limited space to be causal and flexible. The questions are structurally laid out before the interview and the interviewer must comply with the sequence of the questions as well as the wording during the interview process. The interviewee is not allowed to disagree/agree or provide suggestions for an answer. A semi-structured interview provides more flexibility to the interviewer and interviewee as they do not have to strictly comply with a set of processes. The semi-structured interview does have a set of questions planned out for the interview but based on the interviewee's responses, a researcher can ask further questions to enrich the collected data and retrieve an in-depth understanding of the problem that is being investigated. This interview type can be conducted in a group or individually. An unstructured interview does not have a list of questions planned out prior to the interview and this type of interview is commonly used by ethnography researchers. It can be described as a conversation that is controlled based on the researcher's interest (Adhabi & Anozie, 2017). In this research study, a semi-structured interview was a data collection method as it provides the interviewer and respondents with more flexibility during the interview process.

3.4.4 Pre-testing

Pre-testing is a technique that allows the researcher to mimic the data collection process on a small set of the sample population to identify any potential problems with the data collection method. It is an effective approach to ensure that the research questions is answered through the proposed surveys and questions. Pre-testing can also assist in ensuring that the questions are aligned ethically and would not offend the interviewee (Hurst et al., 2015). A cognitive interviewing strategy was used to pre-test the survey for this study.

Cognitive interviewing is a pre-testing method that assists the researcher in studying how the respondents comprehend and process the questions mentally and respond. It has been widely used to evaluate the quality of a survey questionnaire. Think-aloud is an interview pre-testing technique that allows the interviewer to read the questions out to the respondents and capture the answer on an audio recorder or make notes of the mental process that the respondents used to get to the answer (Willis, 2005). The concurrent think-aloud technique allows participants to vocalise (think-aloud) their answers to a question being presented to them (Hurst et al., 2015); consequently, the concurrent think-aloud interviewing technique was used to ensure that the respondents fully understand the questions during the interviews.

When designing the survey questionnaire, the researcher used the following checklist provided by Sarah (2020) to generate the questions:

- Comprehension: The participant can easily understand the purpose of the survey and the interview. The wording used is easy to interpret.
- Acceptability: The question that is being asked as part of the interview does not offend or hurt the participant's feelings.

- Length and adherence: The survey and the interview process are not very long with regard to time. The researcher aims to keep the questioning process short to ensure that the respondent does not get bored.
- Technical Quality: The online survey that was disturbed was designed using a reliable survey technology that does not result in technical glitches.
- Gaining Consent: As part of the introduction of the survey, the required consent was collected from the participant to ensure that the research study is ethnically inclined.

As part of the pre-testing of the questionnaire, the survey was distributed to three participants to ensure that the questionnaire met the checklist criteria provided by (Sarah, 2020).

Upon completion of the questionnaire, the participants were required to answer the following questions: (1) Is the language used in the questionnaire understandable? (2) Was the survey clear? (3) How long did it take you to complete the questionnaire? Table 6 provides the pre-testing result for the questionnaire.

Table 6: Pre-Testing Result

Question	Academic Lecturer	Participant 1	Participant 2
1. Is the language used in the questionnaire understandable?	Yes	Yes	Yes
2. Was the questionnaire clear?	Yes	Yes	Yes
3. How long did it take you to complete the questionnaire?	eight minutes	three minutes	four minutes

Based on the above result data, 100% of the participants found the language understandable, 100% found the questionnaire clear and it took an average of four to seven minutes to complete the survey. Based on the pre-testing result, the researcher concluded that the pre-testing was a success and the questionnaire, as designed, was then used to collect data on IoT device usage experience.

3.5 DATA ANALYSIS

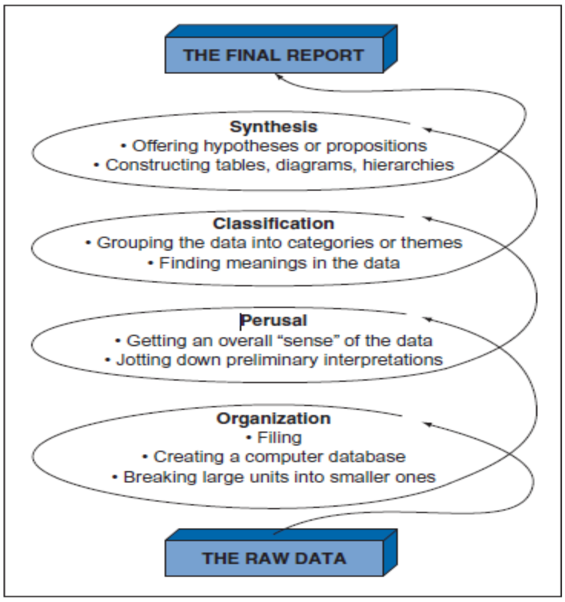
As mentioned above, analysing the collected data is a challenging process in a qualitative study and as highlighted by Brent and Leedy (2015), analysing qualitative data is an iterative process. The Data Analysis Spiral method by Creswell (Brent & Leedy, 2015) was used to analyse the collected data in this research study. This method allows a qualitative researcher to go through the dataset more than once. The following steps that are included in Creswell's approach were taken to prepare and analyse the qualitative data from the semi-structured interviews (Brent & Leedy, 2015):

1. ***Organisation***: The collected data was organised electronically in folders created for different participants and each data collection method. All audio files were transcribed. The collected data was stored electronically on a computer and a backup was created on *Google Cloud* to prevent data loss.
2. ***Perusal***: The collected data was reviewed several times to thoroughly understand the dataset. As part of the reviewing and comprehending phases, initial interpretations and thoughts were written down in a document for possible categorising and coding. An inductive coding process was used to derive themes from the collected raw data. Inductive coding can be defined as identifying themes or concepts after the researcher has reviewed and analysed the raw data iteratively (Thomas, 2003).
3. ***Classification***: In this phase, the collected data was categorised based on identified themes and patterns in the data set. A coding method was be used to categorise the data into codes accordingly.
4. ***Synthesis***: The analysed data was concluded and summarised for any future readers of the research study. In this phase, the selected theoretical framework was used to analyse and conclude the findings of the research study.

As mentioned by Sandelowski (2001), counting is an important aspect of the data analysis process in qualitative research because it assists with adding clarity to identified patterns or themes. In this research, the counting method was used to sum up the participants' responses and the occurrence of an identified code/theme in the questionnaire and semi-structured interviews.

Figure 3 denotes the process that was utilised to process the raw data collected for research study and convert it into the data that was used during the data analysis.

Figure 3: The Data Analysis Spiral



Source: (Brent & Leedy, 2015)

For the questionnaire data analysis, content analysis had been used to derive common categories from the open-ended questions. As stated by Elo and Kyngäs (2008: 108), content analysis can be defined as "... Content analysis is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge, new insights, a representation of facts and a practical guide to action".

3.6 ETHICS

The rights of the participants and the responsibilities of the researcher were presented to the participants and the case study organisation in an *MS Word* document. Written consent was obtained before the required data was collected.

As part of this research study, the following rights of the participants suggested by Oates (2006) were included:

- The participants had the right to give informed consent: The researcher ensured that the participants had in-depth detail regarding the goal of the research, the researcher's details (personal details), what the participants would be required to do and the time it would take to complete the activity, any expenses or incentives related to this research and how the data that is collected was processed. If the participant is comfortable with the shared details on the research, he/she had the right to give informed consent. The consent was be captured on a document.
- The participant has the right not to participate in the research: Participants were not forced to participate in the research project and have the right to refuse.
- The participant has the right to withdraw from the research at any time. The participant could refuse to answer certain questions as part of the semi-structured interview.
- The participant has the right to confidentially: The data was collected using the proposed data collection method was kept securely on a password-protected computer with the required anti-virus software installed to prevent hackers from stealing the data. *Google Drive* was be used to store the collected data generated during as part of this research. If the participants request for certain information not to be shared, then the information was not included as part of the research report.
- The participant has the right to remain anonymous (If so requested). If the participant is not comfortable with disclosing their details (such as name and job positions), their details was not included; they were included as anonymous in this research report. The case study organisation's identity was not included in the research paper.

The following ethics responsibilities of the researcher suggested by Oates (2006) were taken into account by this researcher when conducting the research:

- The researcher shall behave with integrity: As part of this research, the data was recorded truthfully and the data was not be manipulated to suit the researcher's goal. The participants were made aware of what the researcher plans on doing with the data and identify how the research results can benefit the participants as well. As mentioned above, the necessary action were taken to protect the participant's data.

- The researcher shall not unnecessarily intrude on the participants: While collecting the required data, the researcher shall not ask for details that add no value to the findings of the research report. The researcher refrained from asking unnecessary questions as part of the semi-structured interview.
- The researcher shall abstain from performing plagiarism by not taking credit for someone else's work and where applicable, the author were referenced to avoid plagiarism.
- The researcher shall follow a suitable professional code of conduct: To guide the researcher in making ethical decisions during this research, the Association for Computing Machinery (ACM) was followed, regarding the applicable code of conduct. In addition, ethical clearance was obtained (EBIT/18/2022) from the University of Pretoria for conducting this research study.

3.7 CONCLUSION

This chapter detailed the research design, sampling method, data collection method, data analysis method and research ethics that were implemented in this study. The chapter summarises the methods and strategies that were utilised during the research.

Interpretivism was selected as the research paradigm because it was an adequate choice for this research as it allowed the researcher to understand how a person or group perceives their world. In addition, to answer the research question, the goal is to comprehend and identify the perceptions of the end-users related to IoT devices. Based on the selected paradigm, a qualitative research approach was selected for the study. The motivation for selecting the qualitative method as a research approach for this study was because it would assist in comprehending the identified phenomena in detail. A case study approach was the research strategy selected for this study. The motivation for selecting a case study was for this research paper, a specific type of smart IoT device and location would be used to investigate the implementation of HCI principles on an IoT device and how effective they were.

A non-probabilistic sampling method was used to select the sample for this study. The two types of participants who were selected for this study were smart home device consumers and employees from the organisation that were a part of the case study. A triangulation method was used to gather the required data for the study. The study used two data collection tools, namely questionnaires and semi-structured interviews. The two sampling methods utilised for this research study were self-selection and quota sampling. The sample size for the questionnaire was 57 and ten organisation employees were interviewed as part of this research. A cognitive interviewing strategy was used to pre-test the questionnaire with the test sample. To analyse the collected data, Creswell's data analysis spiral method was used to analyse the collected data in this research study (Brent & Leedy, 2015).

CHAPTER 4: ANALYSIS OF FINDINGS

4.1 INTRODUCTION

The purpose of data analysis is to review the data collected by the researcher and derive meaningful information using different analysis methods e.g., grounded theory. (Oates, 2006). Data analysis is one of the crucial steps in qualitative research as it has a direct impact on the research results. This step can be performed at different stages of the research process. There are different analysis methods available for a qualitative researcher to utilise as part of the analysis phase (Mayer, 2015). This chapter will provide the data analysis results for the questionnaire and semi-structured interview. Smart home device owners were requested to complete the questionnaire. The Likert scale was used to design seven questions for the questionnaire. A counter method was used to calculate the participants' responses and the occurrence of identified codes/themes in the questionnaires and semi-structured interviews. Content analysis was utilised to analyse the open-ended questions of the questionnaire, to identify categories and report on the frequency count of a category, based on the participants' responses.

As part of this research study, the questionnaire results will be presented in a suitable visualisation method to answer the existing challenges faced by IoT consumers in relation to device usage, data collection and security element. The organisation's employees who could be involved in the design of an IoT device were requested to participate in the semi-structured interviews. The coding categories method was used to extract common themes from the semi-structured interview data and report on the findings.

The purpose of this project is to study the principles of HCI in smart home devices. The study was conducted in South Africa and the participants required for the study were consumers who possess a smart home device and skilled experts who provided feedback on what components are important in building an IoT device. The main research question was answered in this research:

"What *are the principles of the Human–Computer Interface in Internet of Things (IoT) devices?"*

The objective is to study the benefits and challenges of using a smart home device, security and privacy concerns related to the smart device, accessing the information generated by the smart device and adding to the existing body of knowledge related to building computation devices around HCI principles.

4.2 FINDINGS AND ANALYSIS – QUESTIONNAIRE

4.2.1 Smart Device Information

The questionnaire was used as a data collection medium to gather the smart device information from the participants. The purpose of collecting smart device information was to understand what types of smart home devices are commonly used in a household and what the motivation for purchasing the devices were. The questionnaire was designed to capture experiences and concerns per smart home devices because different devices can provide different user experiences based on their functionality, the number of years the participant have had the device and the manufacturer of the device. Under the smart device information section, the participants were required to provide the following smart home device details: type of smart home device, the number of years the participants have had the device, the brand of the smart home device and the reason for purchasing the smart home device. This section contained open and close-ended questions. The questionnaire sample included fifty-seven participants who owned a smart home device.

The first question in the questionnaire focused on collecting the smart home device type detail in order to compile a profile of the respondents. The purpose of collecting the device type was to highlight the type of smart device commonly used within a household and to build the required context for the user experience. Each device type provides its own set of functions and benefits to the user based on the use case. It is imperative to comprehend the types of devices that the participants are utilising to further highlight the challenges and concerns raised by the user pertaining to the device. Table 7 provides a summary of the responses provided by the participants on the different smart home devices installed in their homes. The most common type of smart home device was a smart television (TV) with 68.42 % (39), representing more than half of the responses. Smart lights were the second most common type of smart home device with 8.77% (5) of the responses and the third most common type of smart home device was smart speakers with 7.02% (4) of the responses. One of the participants had a complete set-up of a smart home from the same device manufacturer. The summary provided in Table 7 displays that the entertainment category is a popular device type installed in homes.

Table 7: Smart Device Type (Researcher's analysis)

Smart Device Type	*Respondent Count*	*Percentage*
Smart Air fryer	2	3,51%
Smart Blinds	1	1,75%
Smart Camera	1	1,75%
Smart Home (Lights, Plugs, Sensors, Television, Speakers, etc.)	1	1,75%
Smart Lights	5	8,77%
Smart Plugs	2	3,51%
Smart Refrigerator	1	1,75%
Smart Speaker	4	7,02%
Smart Television	39	68,42%
Smart Streaming Player	1	1,75%
Total	*57*	*100%*

The second question under the smart home device information section focused on gathering data on how long the participant have had the smart home device. The purpose of collecting this data was to understand the experiences of participants concerning the usage and maintenance of the smart device. The smart device experience data can also assist with building the required context of the device usage and the useability experience of respondents with the device. As part of the second question, the participants were provided with four options; 0–2 years, 2–5 years, 5–7 years and 7+ years. Table 8 provides a summary of the responses related to device usage experience which includes the total count as well the sample percentage detail. Around 42.11% (24) of the participants had been using the smart device for 0–2 years, 38.60% (22) of the participants had been using the smart device for 2–5 years, 14.04% (8) of the participants had been using the device for 5–7 years and 5.26% (3) of the participants had been using the smart device for 7+ years.

Table 8: Smart Device Usage Experience (Researcher's analysis)

Number of Years	*Respondent Count*	*Percentage*
0–2 Years	24	42,11%
2–5 Years	22	38,60%
5–7 Years	8	14,04%
7+ Years	3	5,26%
Total	*57*	*100%*

The third question under the smart device information section focused on collecting data on the device brand. The purpose of gathering brand information was to identify the popular smart home device brands in a home as well as to identify correlations between the motivation for purchase and user perception of the device's security. In a previous study conducted by Zheng et al. (2018), the research results concluded that the user's purchase motive for smart devices and trust in the device with regard to the privacy elements were linked to the device manufacturer. The participants were provided with a pre-defined option that included popular smart home device brands and the 'other' option where the participants were allowed to enter brands not included in the pre-defined option. Table 9 provides a summary of the responses related to the smart home device brand that includes the total count as well the responses' percentage detail. The most popular smart home device brand in a household was Samsung at 40.35% (23), representing almost half of the responses. The second most common brands were Google and Skyworth LG with 7.02% (4) of the responses and the third were Hisense and Amazon, with 5.26% (3) of the responses. A variety of other device brands were provided by the participant as part of the questionnaire.

Table 9: Smart Device Brand (Researcher's analysis)

Smart Device Brand	***Respondent Count***	***Percentage***
Amazon	3	5,26%
Apple	1	1,75%
Bneta	1	1,75%
Connex Connect	1	1,75%
FryAir	1	1,75%
Google	4	7,02%
Harmon Kardon	1	1,75%
Hisense	3	5,26%
LG	4	7,02%
Phillips	1	1,75%
Qualitel	1	1,75%
Samsung	23	40,35%
Siemens	1	1,75%
Skyworth	4	7,02%
Sonoff	1	1,75%
Sony	1	1,75%
Syinix	1	1,75%
TP-Link	1	1,75%
Vizia	1	1,75%
Wyze	1	1,75%
Xiaomi	2	3,51%
Total	*57*	*100%*

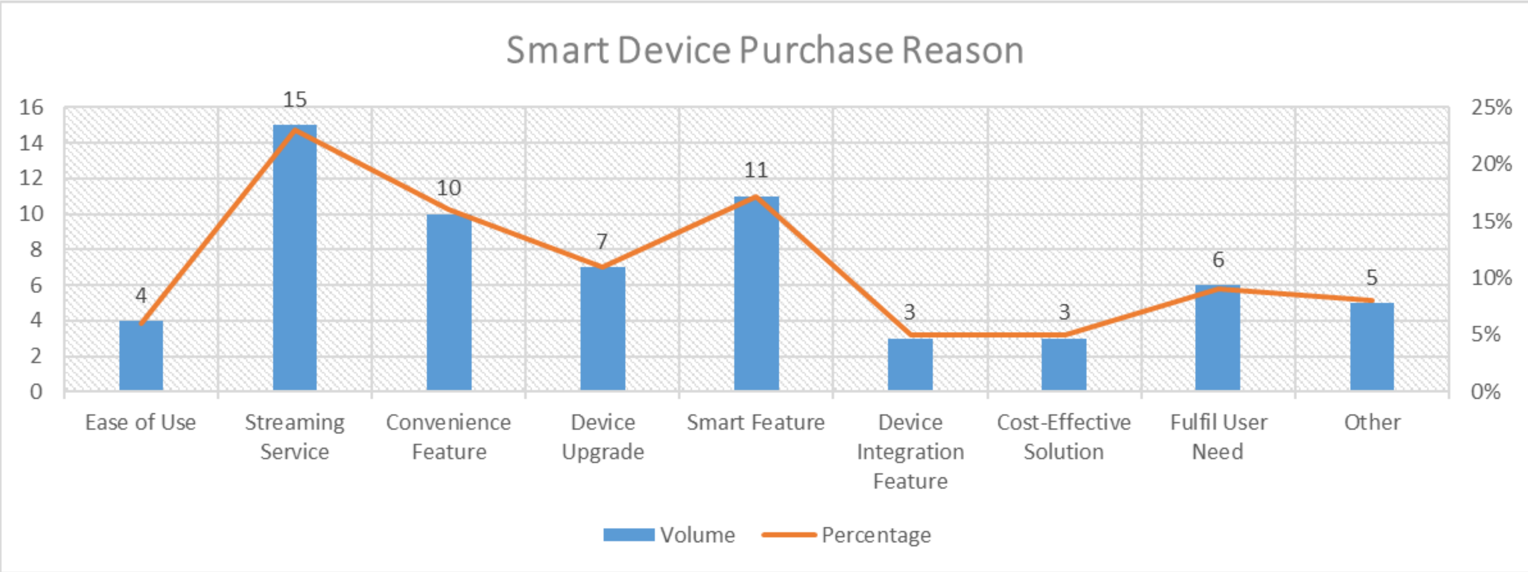
The fourth and final question under the smart device information and respondent profile section focused on capturing and analysing the motivation for purchasing a smart home device instead of a traditional device. The question could also assist in providing common reasons that IoT device designers could consider while building IoT devices and meeting users' needs. The participants were required to answer the following question, "Why did you purchase the smart home device?" It was an open-ended question and users were provided with a free text field to enter their answers. To analyse the responses, qualitative content analysis was used to derive common categories/themes from the participants' responses.

Figure 4 provides a visual representation of the identified categories through a clustered column chart type as the visual representation method. The categories were identified by thoroughly reviewing the participants' responses. After the categories had been successfully identified, the individual responses were reviewed and a point was recorded if the response matched any of the identified categories. A frequency count was then utilised, to sum up the total for each category. The category percentage was derived by dividing the total of the categories by the total response category count. Figure 4 was generated using the total of each identified category. As part of the analysis, nine categories were identified: ease of use, streaming service (e.g., *Netflix*), convenience feature, device upgrade, smart feature, device integration feature, cost-effective solution, fulfilling user needs and 'other'.

The smart feature category included features that are not available on traditional devices (e.g., connecting to devices wirelessly, monitoring functionality or adjusting the temperature of a smart fridge). The 'other' category contained the following purchase reasons: improved security provided by the smart device, not being 'tortured' by the local entertainment provider (e.g., DSTV), exploring smart home devices and the user receiving the device as a gift. The most common reason for purchasing the smart device was the streaming service feature (23% [15]) that allows users to stream services like *Netflix* and *YouTube* on their smart televisions (TVs). The second common reason was the smart feature (17% [11]) which allowed the user to connect the device to the internet, manage the device remotely and having access to monitoring capabilities.

The third common reason was the convenience feature (16% [10]) which allowed the user to have all streaming services in one place, flexible solutions for managing smart lights when the user is not at home, simplifying the participant's daily tasks like cooking and monitoring electricity consumption.

Figure 4: Smart Device Purchase Reason (Researcher's analysis)



4.2.2 Smart Device Usage and Maintenance

The second section of the questionnaire focused on collecting data related to the end user's smart device user experience and the maintenance of the device. This section allowed the participants to provide feedback on the device experience, highlight challenges with using or maintaining the device, and the method they utilised to maintain and operate the smart device. The purpose of collecting data on user experience was to understand the current state of the art regarding IoT device usage and the problems faced by the end user who have had the smart device installed in their house for a period of time. By reporting on the challenges faced by the end user, the IoT device designer could consider the factors and address them during the build stage of the IoT device. It is also crucial to collect device usage experience data as the end user is the ultimate user of the device and the IoT device should meet the user's needs.

The first statement under the smart device usage and maintenance section focused on collecting data related to the difficulty level for setting up and installing smart devices in participants' homes. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement for a given statement.

The participants were provided with the following statement:
"*The smart device was easy to set up and install*".
Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree.
Table 10 provides a summarised representation of the participants' responses to the statement. A tabular format is used to display the response summary and the count of the agreement level (e.g., strongly agree) is used to populate the table. Around 52% (30) of the respondents agreed that the smart device was easy to set up and install. Around 45.61% (26) respondents strongly agreed that the smart device was easy to set up and install. Only 1.75% (1) disagreed that the smart device was easy to set up and install. The strongly disagree and neutral options were not selected by any participants. Based on the summary provided in
Table 10, 98.24% (56) found the initial set up and installation of the smart device easy.

Table 10: Smart Device Installation (Researcher's analysis)

	Disagree	Agree	Strongly Agree
Percentage	1.75%	52%	45.61%
Total Number	1	30	26

The second statement under the smart device usage and maintenance section focused on collecting data related to end-user satisfaction levels concerning the smart device. The device manufacturer must ensure that the smart device has simplified the end user's life and met the user's needs and expectations. The purpose of this statement is to analyse and understand the current user satisfaction level with the smart home product. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement with the given statement.

The participants were provided with the following statement:
"*The smart home device met my expectation and needs*".

Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree. Table 11 provides a summarised representation of the participants' responses to the statement. A tabular format is used to display the response summary and the count of the agreement level (e.g., strongly agree) is used to populate the table. Around 49% (28) strongly agreed with the statement, 33.33% (19) agreed with the statement, 15.79% (9) felt neutral about the statement and 1.75% (1) disagreed with the statement. Based on the summary provided in Table 11, 82.45% (37) of the participants are satisfied with their smart home devices installed within their homes and the smart devices have met their expectations and needs.

Table 11: User Expectations and Needs (Researcher's analysis)

	Disagree	Neutral	Agree	Strongly Agree
Percentage	1.75%	15.79%	33.33%	49%
Total Number	1	9	19	28

The third statement under the smart device usage and maintenance section focused on collecting data related to the daily usage and maintenance of the smart device within a household environment. After the initial installation of the smart device, participants may have faced challenges while utilising the device on a day-to-day basis. The purpose of this statement was to further understand if the end user found the maintenance of the device difficult. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement with the given statement.

The participants were provided with the following statement:

"*The smart home device is easy to use and maintain.*"

Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree. Table 12 provides a summarised representation of the participants' responses to the statement. A tabular format was used to display the response summary and the count of the agreement level (e.g., strongly agree) was used to populate the table. Around 52% (30) of the respondents strongly agreed with the statement, 42.11 % (24) of the respondents agreed with the statement, 3.51% (2) of the respondents were neutral about the statement and 1.75% (1) respondent disagreed with the statement. Based on the summary provided in Table 12, 94.74% of the respondents found it easy to use and maintain the smart devices in their homes.

Table 12: Smart Device Usage and Maintenance (Researcher's Analysis)

	Disagree	Neutral	Agree	Strongly Agree
Percentage	1.75%	3.51%	42.11%	52%
Total Number	1	2	24	30

The fourth question under the smart device usage and maintenance section focused on capturing the challenges faced by the end user while utilising the smart device. The purpose of this question was to highlight current challenges faced by the end user while utilising the smart home device. The IoT device designer can utilise the information to consider the highlighted challenges while building the device and implement the required solution to resolve the challenges. It was an open-ended question where the participants were provided with a free text field to enter their answers. To analyse the responses, qualitative content analysis was used to derive common categories/themes from the participants' responses. The participants were required to answer the following question: "*Please specify any challenges faced with using the smart home device.*"

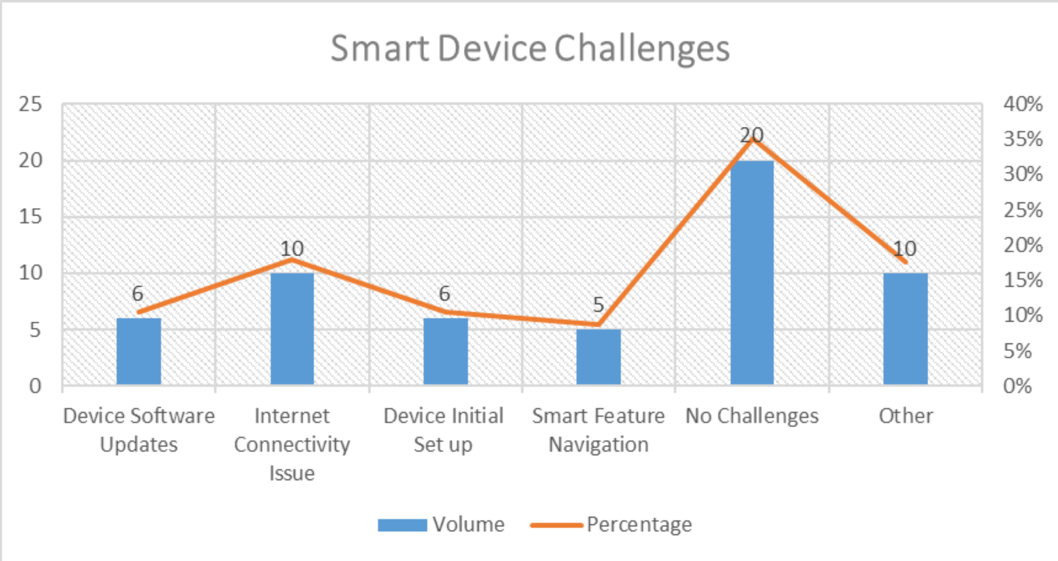
Figure 5 provides a visual representation of the identified categories. The clustered column chart type was used as the visual representation method. The categories were identified by thoroughly reviewing the participants' responses. After the categories had been successfully identified, individual responses were reviewed and a point was recorded if the response matched any of the identified categories. A frequency count was then utilised to sum up the total for each category. The category percentage was derived by dividing the total of the categories by the total response category count. Figure 5 was generated using the total of each identified category. Six categories were identified: device software updates, internet connectivity issues, device initial setup, smart feature navigation, no challenges and 'other'.

The device software updates category included challenges related to software updates that either took place too often that didn't enhance the current device experience or in some cases, the lack of software updates was highlighted and which prevented end users from using the latest applications. A participant was unable to perform any type of update due to the software installed on the device. The internet connectivity issue category included challenges related to smart device stable connectivity with the home Wi-Fi, unable to make use of any application on the smart device due to a lack of internet connectivity, smart device being disconnected from the internet and taking a few hours before the device is successfully connected to the internet again, as well as the home Wi-Fi distance issue. The device initial set-up category included challenges related to poor instruction provided by the manufacturer to set up the device, the end user being required to have coding skills (e.g., Python) to complete the initial configuration of the smart device, losing device settings due to power loss and having to reconfigure them, and setting up the devices on the home Wi-Fi and 'buggy' firmware.

The smart feature navigation category included challenges related to exploring all the available functionalities available on the smart device because respondents found that confusing and struggled to navigate the smart device. One of the respondents found the search functionality that is available on the smart television (TV) ineffective and preferred a touch screen as an interaction method with the device. The other categories included issues related to inaccurate voice control, lack of electricity leading to problems for smart fridges, the *Alexa* application not being available in South Africa which leads to difficulties with installation and device management, smart devices not meeting user performance expectations, security issues, remembering account credentials and the end user not being aware that the device connects to the internet.

Around 35% (20) of the respondents had no problems while using the smart device. Around 17% (10) of the respondents mentioned the internet connectivity issue, 10.53% (6) of the respondents highlighted device software updates as a challenge, 10.53% (6) highlighted the device initial setup as a challenge, 8.77% (5) of the respondents highlighted smart feature navigation as a challenge and 18% (10) of the respondents' concerns were included in the 'other' category.

Figure 5: Smart Device Challenges (Researches Analysis)



The last question under the smart home device usage and management section focused on collecting data related to a smart device management tool. The purpose of collecting device management tool data was to identify a common smart device management tool that an end user had used to configure device settings and view device usage history. Identifying the device management tool could assist the IoT device designer with taking the areas where further enhancement could be included into account, to improve the users' experience of the smart device. A smart device management tool is also used to display device usage data and identifying a common management tool could guide the device designer to build user interfaces that display information that might aid end users in effective decision-making. The participants were presented with the following options: via a mobile application, an online website, the smart home device and the 'other' option where the participants were allowed to enter management tools not included in the pre-defined options.

Table 13 provides a summary of the responses provided by the participants on a smart device management tool. The most common management tool is the smart home device with 54.39 % (31) of the responses. The second common management tool is a mobile application with 35.09% (20) of the responses. The third most common management tool is remote access with 8.77% (5) of the responses. One of the participants used a home assistant to manage their smart home device.

Table 13: Device Management Tool (Researcher's Analysis)

Device Management Tool	*Respondent Count*	*Percentage*
Remote	5	8,77%
Home Assistant	1	1,75%
Via a mobile application	20	35,09%
Via the smart home device (e.g. button built on the smart home device)	31	54,39%
Total	*57*	*100%*

4.2.3 Smart Device Data Collection

The third section of the questionnaire focused on collecting data concerning smart device data collection and presentation. The purpose of this section was to understand if end users were aware of the smart device data collection function, have access to the device data and if the presented data is easy to comprehend. As the smart device is placed in a personal home setting, it has the capability to constantly record usage data. The data collected by the smart device is in a raw format and to convert the raw data into useful confirmation, smart device manufacturers use technologies like artificial intelligence and machine learning to provide valuable feedback to the end user, which can then assist them with sound decision-making.

The first statement under the smart device collection section focused on identifying if the end user is aware that data is being collected. For the end user to access the device usage data, he/she would need to be aware that the smart device is collecting data that is available for review at a later stage, based on the device manufacturer's solution. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement with the given statement.

The participants were provided with the following statement:
"*I am aware that my smart device collects usage data".*
Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree. Table 14 provides a summarised representation of the participants' responses to the statement. A tabular format was used to display the response summary and the count of the agreement level (e.g., strongly agree) was used to populate the table. Around 40.35% (23) of the respondents strongly

agreed with the statement, 40.35 %(23) of the respondents agreed with the provided statement, 5.26 % (3) of the respondents were neutral about the provided statement, 8.77% (5) respondents disagreed with the provided statement and 5.26% (3) strongly disagreed with the provided statement. Based on the summary provided in Table 14, more than 80% of the end users were aware that the smart device was collecting usage data. Around 13% of the end users disagreed with the statement and were not aware that the smart device is collecting usage data.

Table 14: Data Collection Awareness (Researcher's Analysis)

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Percentage	5.26%	8.77%	5.26%	40.35%	40.35%
Total Number	3	5	3	23	23

The second statement under the smart device collection section focused on collecting data on user access to device usage data. The end user might be aware of the smart device collecting data but he/she might have not access to it. The purpose of collecting data concerning smart device data access was to ascertain whether the end users could access the usage data and review what types of data were collected. By having access to usage data, end users also have the opportunity to maintain that data if they feel uncomfortable with the collected data. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement with the given statement.

The participants were provided with the following statement:
"*I can access my smart home device usage data".*
Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree or strongly disagree. Table 15 provides a summarised representation of the participants' responses to the statement. A tabular format was used to display the response summary and the count of the agreement level (e.g., strongly agree) was used to populate the table. Around 28% (16) of the respondents agreed with the provided statement, 28.07% (16) of the respondents disagreed with the provided

statement, 21.05 % (12) of the respondents were neutral about the provided statement, 17.54% (10) of the respondents strongly agreed with the provided statement and 5.26% (3) strongly disagreed with the provided statement.

Table 15: Smart Device Usage Data Access (Researcher's Analysis)

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Percentage	5.26%	28.07%	21.05%	28%	17.54%
Total Number	3	16	12	16	10

The third statement under the smart device data collection section focused on identifying methods that the end user utilises to access device usage data. The purpose of collecting data pertaining to the usage data access method was to identify the preferred and common method utilised by end users to view and manage device usage data. The participants were presented with the following options: via mobile application, the device (e.g. screen built up on device displaying usage details), an online website and 'not applicable as I do not have access to the device usage data'.
Table 16 provides a summary of the responses provided by the participants on smart device usage data access. The most common usage data access tool was the smart device with 29.82% (17) of the responses. The second common usage data access tool was a mobile application with 24.56% (14) of the responses. The third common usage data access tool was an online website with 5.26% (3) of the responses. Around 40% (23) of the participants selected the 'not applicable' option as they did not have access to the device usage data.

Table 16: Data Access Tool (Researcher’s Analysis)

Data Access Tool	*Respondent Count*	*Percentage*
Not applicable as I do not have access to the device usage data.	23	40,35%
Via an online website	3	5,26%
Via mobile application	14	24,56%
Via the device (e.g., screen built up on device displaying usage details)	17	29,82%
Total	*57*	*100%*

The last statement under the smart device data collection discussion focused on determining whether the end user found the presented device usage useful in their daily lives and if the information presented was easy to comprehend. The statement was designed using the Likert scale method where the participants were required to provide their level of agreement with the given statement.

The participants were presented with the following statement:
"*The device usage data is useful and easy to comprehend".*
Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree. Table 17 provides a summarised representation of the participant's response to the statement. A tabular format displays the response summary and the count of the agreement level (e.g., strongly agree) was used to populate the table. Around 42%(24) of the respondents were neutral about the provided statement, 22.81% (13) of the respondents agreed with the provided statement, 17.54 % (10) of the respondents disagreed with the provided statement, 14.04% (8) of the respondents strongly agreed with the provided statement and 3.51% (2) strongly disagreed with the provided statement.

Table 17: Smart Device Usage Data Presentation (Researcher's Analysis)

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Percentage	3.51%	17.54%	42%	22.81%	14.04%
Total Number	2	10	24	13	8

4.2.4 Smart Device Security

The last section of the questionnaire focused on capturing data related to security concerns that end users might have concerning smart home devices. Because smart home devices are collecting and storing device usage related to that, it is imperative to ensure that the collected data is secured and protected from external threats (Ndubuaku & Okereafor, 2015). Smart home devices are placed in personal home settings and those devices could collect private data which end users might not be comfortable sharing with the device manufacturer (Ammari et al., 2019).

The first statement under the smart device security section focused on the study's collected data related to discovering whether end users have any security concerns related to their smart devices. Based on the function that the smart home performs, the level of security concern might differ. The purpose of the collected data pertaining to security concerns around devices was to identify how comfortable end users were with a smart home device inside their homes. The statement was designed using the Likert scale method whereby the participants were required to provide their level of agreement with the given statement.

The participants were provided with the following statement:
"*I have security related concerns with using the smart home device.*"
Participants were required to make a selection from the following options: strongly agree, agree, neutral, disagree and strongly disagree. Table 18 provides a summarised representation of the participant's response to the statement. The tabular format displays the response summary and the count of the agreement level (e.g., strongly agree) was used to populate the table. Forty-two per cent (24) of the respondents disagreed with the statement, 22.81% (13) of the respondents were neutral, 12.28% (7) of the respondents agreed, 12.28% (7) strongly disagreed and 10.53% (6) strongly agreed.

Table 18: Security Concerns (Researcher's Analysis)

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Percentage	12.28%	42%	22.81%	12.28%	10.53%
Total Number	7	24	13	7	6

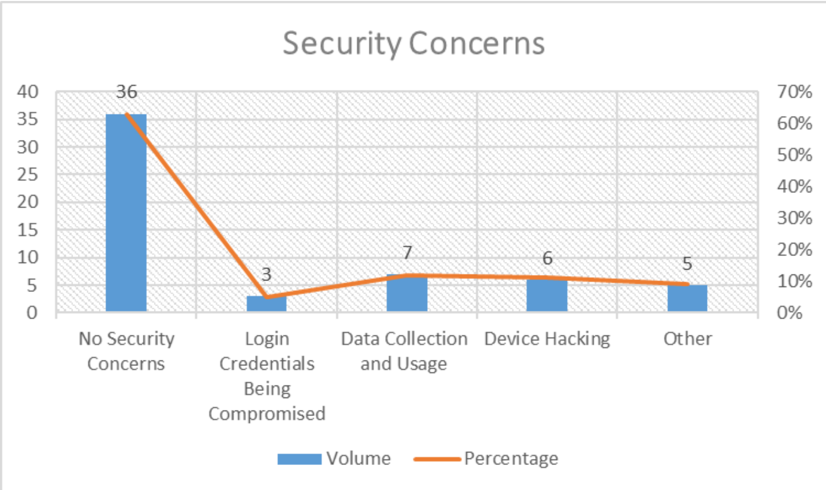
The last question under the smart device security section focused on collecting any concerns that the end users wanted to highlight as relates smart device security. The purpose of the question was to identify and understand which security factors related to smart devices cause concern. It was an open-ended question where the participants were provided with a free text field to enter their answers. To analyse the responses, qualitative content analysis was used as a method to derive common categories/themes from the participants' responses. The participants were required to answer the following question: "*Please specify the security concerns related to the smart home device.*"

Figure 6 provides a visual representation of the identified categories through a clustered column chart type. The categories were identified by thoroughly reviewing the participants' responses. After the categories had been successfully identified, individual responses were reviewed and a point was recorded if the response matched any of the identified categories. A frequency count was then utilised to sum up the total for each category. The category percentage was derived by dividing the total of a category by the total of the response category count. Figure 6 was generated using the total of each identified category. As part of the analysis, five categories were identified: no security concerns, login credentials being compromised, data collection and usage, device hacking and 'other'.

The' login credentials being compromised' category included concerns related to the storing of usernames and passwords, with stored passwords easily being accessed and dangerous sites able to access login credentials (*Google* accounts) on the smart device. The data collection and usage category related to device data being collected and sold to third parties, what the collected data is being used for, personal data collection and the purpose of selling the data to external parties. The device hijacking category is related to concerns about cyber threats and viruses, devices being accessed by unauthorised people and devices being hacked by online hackers and gaining remote access to the device, since it is connected to the internet. The other categories included various concerns raised by the participants such as the end user receiving personalised advertisements about products/issues that they might have casually mentioned around the device, the smart device not being digitally secured, constant monitoring by device manufacturers which made the end user uneasy and the lack of a password or any security control for accessing the smart device.

Around 63 %(36) of the respondents had no security concerns related to the smart home device, 5% (3) of the respondents raised concerns around their login credentials being compromised, 12% (7) of the respondents raised concerns around data collecting and usage, 11% (6) of the respondents raised concerns around the smart device being hacked and 9% (5) of the respondents raised concern that fell under the 'other' category.

Figure 6: Security Concern Category (Researcher's Analysis)



4.2.5 Summary

The section above provided a summarised analysis and findings of the questionnaire responses. A questionnaire was utilised to gain insight into the current user experience related to the usage of smart home devices. Smart televisions (TVs) were the most prevalent smart home devices installed in homes. Most of the participants had installed a smart home device in the past five years. The most popular smart home device brand in the households was Samsung. Participants highlighted several reasons for purchasing a smart device instead of a traditional device. The most common reason for its purchase was gaining access to streaming services. Most of the participants agreed that their smart home devices were easy to set up and install. Around 90% of the participants confirmed that the smart home device met their expectations and needs. Most of the participants found their smart devices easy to use and maintain.

Despite the above-mentioned ease of use and maintenance, the participants mentioned several challenges in the questionnaire. The most common of these was the internet connectivity issue. The most common tool for managing the smart home device was the smart device itself. Most of the participants were aware of smart devices collecting usage data but not everyone had access to the usage data. The most common tool for viewing usage data was the smart device. Almost 50% of the participants were neutral about data being useful and easy to comprehend. The participants gave mixed responses about having security concerns around using smart home devices. Participants highlighted several security concerns. The most common security concern was around data collection and what the data was being used for.

4.3 FINDINGS AND ANALYSIS - SEMI-STRUCTURED INTERVIEW

As part of the semi-structured interview, the case study organisational employees were requested to participate. The case study organisation falls under the telecommunication industry. The sample population was selected by requesting employees who were involved in IT product design and build. Employees from the different departments were interviewed to gain an end-to-end understanding of the Information Technology (IT) product build lifecycle. The motivation for selecting the participants in Table 19 was because they had either been involved in new technology design and build phases or worked on integration solutions for new technology. The interviewees were requested to provide their demographic details and answer nine questions related to IoT device design, data collection and device security elements. Ten organisational employees were selected to participate in the semi-structured interviews and were requested to complete the consent form to participate in the interviews. A comprehensive analysis of the transcribed interviews will be presented in this section.

4.3.1 Participant Demographic Data

As part of the semi-structured interviews, participants' demographic and professional details were collected, to understand their professional backgrounds as well as build the required personas for reporting and analysis of the research findings. The participants' job levels, job titles, education and years of experience were collected.

Table 19 provides a summary of the participants' professional and demographic details. The participant column was created to assign a number for reference. The reference would then be used in the analysis and the finding section of the research.

Table 19: Participant Demographic Detail

Participant	Job Level	Job Title	Education	Years' Experience
Participant 1	Senior Specialist	Solution Engineer	BSc (Hons) Computing	9
Participant 2	Specialist	Solution Architect	BA (Information Management)	8
Participant 3	Specialist	Product Designer	BA (Hons) Digital Arts	5
Participant 4	Senior Specialist	Business Analyst	BSc (Computer Science)	21
Participant 5	Senior Specialist	User Experience Designer	BSc IT (Software Engineering)	8
Participant 6	Specialist	Network Engineer	BSc (Electronic Engineering)	2
Participant 7	Management	IT Manager	M Com (Information systems and technology)	14
Participant 8	Senior Specialist	Enterprise Architect	Master (Science)	16
Participant 9	Senior Management	Fintech Manager	Master (Electronic Engineering)	10
Participant 10	Specialist	Product Designer Lead	BA (Hons)	7

4.3.2 Concept Understanding

The first section identified of the semi-structured interview was concept understanding. The theme focused on gathering details of the participants' understanding of the IoT and HCI concepts. The purpose of collecting information about concept understanding was to determine whether the participants sufficiently understood the concept as well as to answer the remaining questions in the interview as those were tightly linked to the HCI and IoT concepts.

The first question under the concept understanding section was:

"How *would you define [the] Internet of Things (IoT)*?"

The question focused on collecting data related to participants' understanding of the IoT concept. Based on the analysis of the transcribed interviews, all the participants had a fair understanding of the IoT concept as it aligned with the definition provided by IBM (2021) and Ndubuaku and Okereafor (2015). Participants described the IoT as a device or a set of devices that connect to the internet via a unique identifier called an Internet Protocol (IP). Participant eight described the IoT:

> *That's a very broad thing. Ultimately, I suppose I would imagine IoT is the amalgamation of the concept of the information highway and, and what you would typically costs as, as smart devices. Anything that performs a particular function that can possibly either participate in a hub or a hive to achieve a set of objectives*. (Participant 8)

One of aims of an IoT device is to enhance the human world(Perera et al., 2013). Participant two highlights the simplification of a user's life in her definition of the IoT below:

> *IoT helps simplify life by connecting different appliances to each other, and making a human intervention much easier. So, in my understanding, IoT for Internet of Things would be having smart devices, both at home and at work, so that you can control it remotely, as well as get notified remotely*. (Participant 2)

Several participants stated that IoT devices share data with other smart devices that assist them in making a decision or fulfilling a task. Participant nine indicated this data collecting and sharing feature and provided an example of an IoT device use case in their below definition:

> *It's anything as like a connection of different systems or devices that can communicate to each other with its own network, or whether it's in a greater network, like for example, … Apple did a lot of thing with your*

Mac and communicates very well to your iPhone kind of thing … from your smart speakers, to you for your smart fridges now, I mean, washing machines, dishwashers … And exchange data in real time, was a very important thing as well, when I think about Internet of Things. (Participant 9)

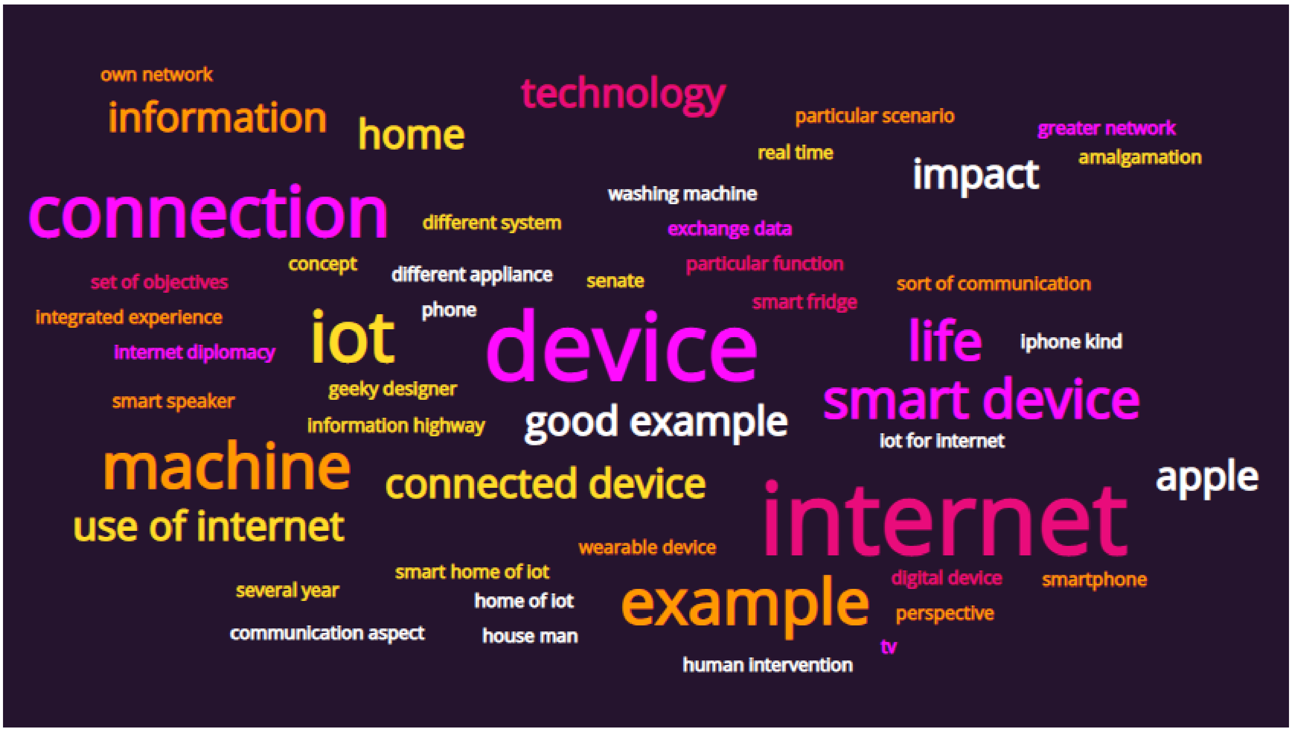
As part of the interview response analysis, three themes were identified: devices that communicate with other devices via local network or the internet, IoT devices that share information with other devices to complete a task or function and simplify users' daily lives. Frequency count was then used to identify the occurrence of each theme in the participant's response. Table 20 provides the summary of identified emerging theme in participants' responses for the definition of the IoT.

Figure 7 highlights the common words that occurred in the participant response. A word cloud generator was used to create the image.

Table 20: IoT Definition Summary (Researcher's Analysis)

Identified Sub Theme	Response Count
Devices that communicate with other devices via the local network or the internet.	10
Devices that share information with other device to complete a task or function	3
Simplifying users' daily life	2

Figure 7: Internet of Things Definition - Word Cloud



The second question under the concept understanding section was:

"What is your understanding of the Human-Computer Interaction (HCI) concept?"

The question focused on collecting data on participants' understanding of the HCI concept. The purpose of asking the question above was to ensure that the participants had a fair understanding of the concept since the upcoming question was linked to it. Based on the analysis of the transcribed interview, all the participants had a basic understanding of the HCI concept and its purpose.

The explanation provided by the participants aligned with the definition provided by Hewett et al. (1992). Participant one provided the following explanation of the HCI concept:

> *Human computer interaction is the way in which people interact with the computer system, and then computer system[s] being the software['s] that we can provide. And also, the sort of physical devices which can either be a mobile, and how easy it is for a, for a user to be able to use*

> *the products that we give to them either via software product or hardware product.* (Participant 1)

Based on the explanation above, Participant one described the Human-Computer Interaction (HCI) concept as the relationship and interaction between the end user and technology. The participant also highlighted the device's ease of use as a focal point of Human-Computer Interaction (HCI).

Participant three highlighted the importance of considering the requisite end-user cognitive load and the mental model while building the device for end users in the concept explanation of Human-Computer Interaction (HCI) below:

> *In a nutshell, it is the study of how humans interact with computers, you know, and the other way around. So, its human computer interaction is not one dimensional is not just about the human or the user clicking on buttons for the computer to do something. It's all got to do with, you know, cognition as well. Just the study of human psychology, as well as a bit of that, which is kind of like also embroiled in in UI/UX design. There's that lens as well. As you need to understand, you know, mental models and stuff like that.* (Participant 3)

30% of the participants also mentioned that the device needs to be built around end users' needs and wants; designers should follow a human-centric approach to building devices.

As part of the interview response analysis for the second question, four themes were identified: HCI defines the relationship and interaction users have with a machine or technology, HCI defines device useability, designing devices in a manner that places users at the centre of the process and the requisite user cognition load to process information or instructions. Frequency count was then used to identify the occurrence of each theme in the participants' responses.

Table 21 provides a summary of the identified emerging themes in participants' responses on their understanding of the HCI concept. Figure 8 highlights common words that occurred in the participants' responses. A word cloud generator was used to create the image.

Table 21: Human-Computer Interaction (HCI) Concept (Researcher's Analysis)

Identified Sub Theme	Response Count
HCI defines the relationships and interactions that users have with a machine or technology.	9
HCI defines device useability.	3
Designing devices in a manner that puts users in the centre.	3
Requisite user cognition load to process information or instructions.	3

Figure 8: Human–Computer Interaction Concept - Word Cloud

4.3.3 IoT Device Usage and Design Experience

The second section under the semi-structured interview was: IoT device usage and design experience. The section focused on collecting data related to the participants' IoT device usage experiences and IoT device design experience. The purpose of collecting data related to the IoT device usage experiences was to understand the current user experience that the participant had while using a smart device. The purpose of collecting data related to device design was to establish whether the participants had previously been involved in designing a smart device. This information assisted the researcher in understanding participants' design experience with building IoT devices.

The first question under the IoT device usage and experience section that the participants were required to answer was:

“Explain your experience with regards to usage of an IoT device.”

The question focused on collecting data related to the participants' user experiences and providing detail about how satisfied they were with the product. Based on the analysis of the transcribed interviews, six of the participants had positive experiences with the smart device that they were currently using and they mentioned that the device had simplified their daily lives with the functionalities they offered (based on the device type). Participant two described their experience with a smart home device:

> *So, my usage of it is very simplified. I do have a smart fridge, dishwasher and washing machine that basically notifies me when there's either an error and I can control it remotely. So, as an example, my fridge I can do like express freezing and all of that and control the temperature of the fridge from my cell phone. For my washing machine, and my dishwasher, it notifies me if there's an error, like rinsing aid to the dishwasher or remove the water from the tumble dryer once it starts drying clothes, it does send me notifications in that sense. But it also makes my life easier because it does notify me when either cycle is finished.* (Participant 2)

Participant ten mentioned that the smart devices were an extension of her.

Four participants did not have good experiences with smart devices and raised the following disadvantages: The instructions provided for setting up smart speakers were insufficient and that less computer literate users may not have the necessary knowledge to set up the smart devices on the same network, smart device compatibility with other manufacturers' smart devices and a smart device like Alexa Echo not being configured for South Africa in the product's early stages. Participant five labelled the smart speaker 'bleeding technology' instead of cutting-edge technology, due to them adopting a product that was brand new to the market.

Participant 9 explained their experience with smart home assistant:

> *Guess the one that I use commonly would be my Google Home assistant and I think it works well. The biggest gap there … it's using your voice, it does struggle with like, some of our accents or inflections,*

*if you wanted to play, for example, an Afrikaans, Portuguese song kind of thing. … Because the artist's name is not in that American Google Voice. So, it does break in there,… I think Google's done good at allowing it to discover other devices. So, for example, like my Chromecast, my IP camera, for example, when I have my Chromecast on my TV, so these things can communicate to each other. And it kind of enriches their environment … And I think now, as I've kind of progressed on this journey, you know, when I look for like a new smart device, I actually check to see if it's compatible with my Google Home assistant, because I don't want to not get another interface, just interface to that. I do see that as gaps in the market. (*Participant 9)

From the experience above, the participant indeed had a good experience but the device struggled to fulfil all the tasks due to the language barrier inherent to the device. The participant also had to keep the device compatibility element continuously in mind when purchasing a new smart device, owing to different interfaces required by different manufactures.

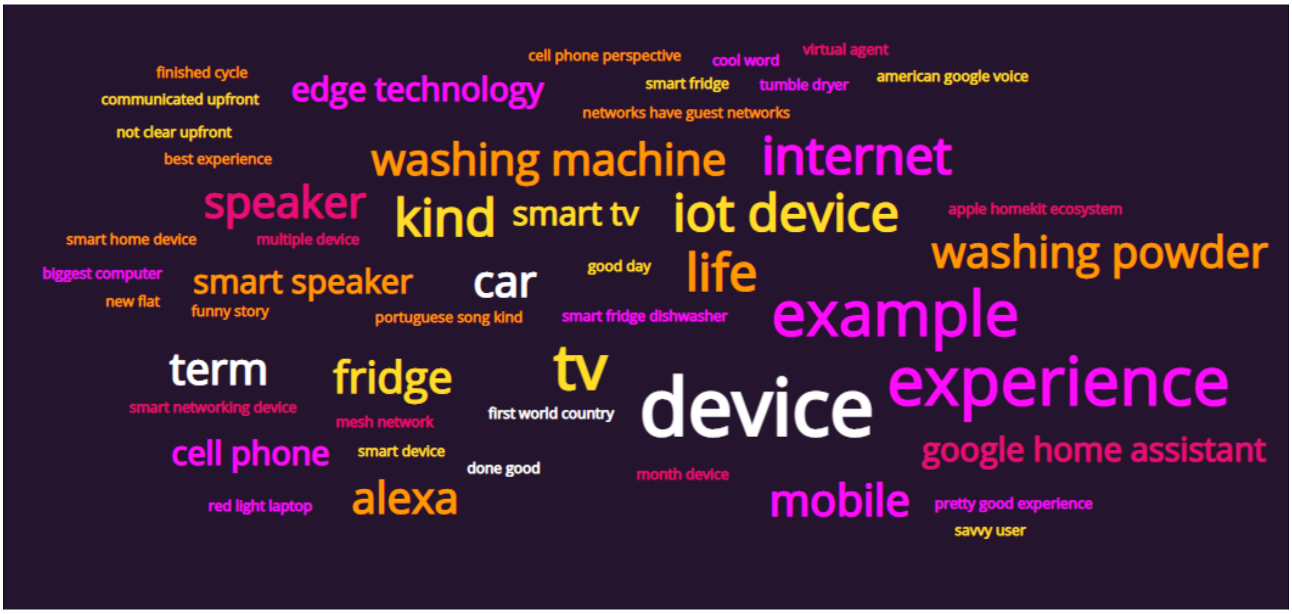
Four themes were identified from the interview responses analysis of the first question: A great experience with no issues and it simplified the participant's life, available functionality on the smart device enhanced user experience, not the best experience as the participant struggled with setting up and using the smart device and over time, the participant learnt how to operate the smart device. Frequency count was then used to identify the occurrence of each theme in the participants' responses.

Table 22 provides a summary of the identified emerging themes in participants' responses for IoT device usage experiences. Figure 9 highlights common words that occurred in the participants' responses. The researcher used a word cloud generator to create the image.

Table 22: IoT Device Usage Experience (Researcher's Analysis)

Theme	Count
Great experience with no issues and it simplified participant's life.	6
Available functionality on the smart device enhanced user experience.	5
Not the best experience as the participant struggled with setting up and using the smart device.	3
Over time, the participant learnt how to operate the smart device.	3

Figure 9: Internet of Thing Device Experience - Word Cloud



The second question under the IoT device usage and experience section was:

"What is your experience in relation to designing of an IoT device?"

This question focused on collecting data related to the participants' design experience with an IoT device. Participants could provide details related to their experiences with IoT physical device build as well as the software that is used by the end users to control the smart device and report on the device usage data. The purpose of collecting IoT design experience data was to understand if the participant has previously been involved in building an IoT device for an end user.

Six out of ten participants had IoT device design experience. These participants have been involved in different stages of design based on their skill sets and expertise. Participant four described their IoT device design experience:

> *One that I've been involved in … It's a device that gets added to a gun. So, it's in the security industry. And then that gun it basically takes video and it can count how many shots is fired. So that little device is connected on a physical device on your, on the pistol, the gun. And then based on movement, you know, obviously streams the video … You know, based on the movement in count the number of shots that was fired and so on. So that if there's security and policing, so that if there's an incident, people know … those immediately what's happening.* (Participant 4)

Participants had been involved in various industries which includes security, household, banking and automotive. Participants worked on the following use cases: IoT device data processing use cases for a smart tracking device that are installed on a vehicle, monitoring a dashboard for smart devices used within a banking industry, smart sensors installed on guns and vehicles, and mobile apps that assist end users to control their smart home. Participant eight provided consulting services on the IoT device data use case and describe the design experience:

> *In terms of some of the data processing, use cases that were there, that is in relation to a chip-based system that monitors you'll get the chips that you install on cars, and vehicles for monitoring certain parameters on the vehicles in terms of consumption, driving style, that kind of thing.* (Participant 8)

4.3.4 IoT Device Design Elements

The third section identified through the semi-structured interviews was IoT device design elements. This section focused on collecting data related to the design factors that should be considered when building a smart device. Participants were required to answer two questions related to IoT device design. The purpose of the section was to identify which factors were currently considered by skilled experts while designing a smart device for end users and their thoughts on incorporating the HCI component in the design stages of a smart device.

The first question under the IoT device design elements section that the participants were required to answer was:

"What are your thoughts on incorporating the human computer interaction component while designing an IoT device?"

The purpose of collecting the data above was to understand if the participants were considering the HCI component when building the device for end users and what their thoughts are on adding the component to the design phase.

Based on the interview transcription analysis, seven participants highlighted that it is an important factor to consider when building smart devices. Participant three highlighted the need to focus on the HCI factor in the device build stage as well building the device around the end user:

> *I think there has been a lot of studies and a lot of research done, you know, a lot of experiments, etc. And I think, like, the IoT space, like, its higher quality, it's technical by nature … Led by, you know, techies … But most developers are mainly concerned with like, code. And the way that they write code, forgetting that whatever that they developing, is going to be used by people in humans. So, you need to, you know, place the human at the centre, … So, I think there needs to be like, heavy involvement, you know, from a UX perspective, or from a product design, perspective, and an ethnography, prospective research, as well,*

> *that's also that, yeah, that's also the key component … But again, what's the point of all that powerful technology, people are not going to be able to use it*? (Participant 3)

From the participant's response, the importance of considering the human factor when building a smart device is noted and explained.

Participants also discussed the device useability factor as well as that the device must be built in a manner that seamlessly integrates with an end user's current lifestyle. Participant ten explains the seamless component in the following statement:

> *I think it's super important because you don't want somebody to have to learn a new thing. I know that technology's you know, generally branded as disruptive, but I don't think technology should disrupt your life, I think it should plug in to what you're doing your normal, … it should just be like an extension of you a continuation of you, which you shouldn't have to stop and learn a new thing and stop and figure something out … So if you're going to have that component baked into IoT, then I think it's going to work brilliantly, because IoT devices usually live in your home. And that's a personal space.* (Participant 10)

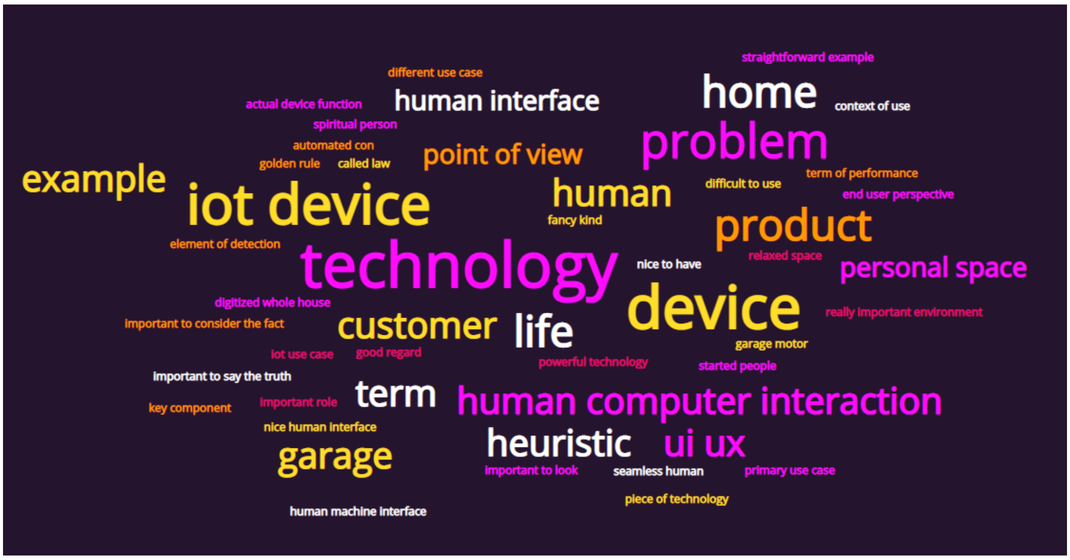
Three themes were identified from the interview response analysis of the first question; an important element to consider when building an IoT device for end users, following a user-centred approach when designing the IoT devices and designing devices that are useable for all types of users (computer literate users or users who are not computer literate). Frequency count was then used to identify the occurrence of each theme in the participants' responses.

Table 23 provides a summary of the identified emerging themes in participants' responses to thoughts on considering the HCI component. Figure 10 highlights common words that occurred in the participants' responses. A word cloud generator was used to create the image.

Table 23: Human-Computer Interaction (HCI) Component (Researcher's Analysis)

Theme	Count
An important element to consider when building an IoT device for end users.	7
Follow a user-centred approach when designing IoT devices.	4
Designing devices that are usable for all types of users (computer literate users or users who are not computer literate).	3

Figure 10: Human–Computer Interaction Component - Word Cloud



The second question under the IoT device design elements section was:

"What are some of the elements you will consider when building an IoT device for end users?"

The purpose of collecting the above-mentioned data was to understand and identify the design elements that are considered when designing a smart device. It also assisted the researcher in identifying if the Human-Computer Interaction (HCI) component is an element considered by the participant when designing the solution.

Participants have different sets of elements that they would consider when designing a device but an important element mentioned was that the device should be easy to use by an end user. Participant four elaborated on the importance of device useability and configuration in the following statement:

> *That the interface that the user use must be very simple. And it must be configurable … you should be able to … clap your hands twice to switch on the lights and want[s] to switch it off, but somebody else might want to say you know, lights on lights off, you know, voice activated so that's what I mean by configuration … when you get to more sort of high-end users or technical inclined users, they would want to configure it.* (Participant 4)

Participants also mentioned the physical device build elements that should be considered when designing a device, the device usage data presentation and the type of use case that they are building for. Participant seven explains the elements that need to be considered when designing an IoT device:

> *You want to ensure that the information that's been given back to the user is in a presentable manner, so that it's easy to understand … the language is available for the person to understand the units of measure relevant to that particular country ... the actual physical device … probably waterproof, and it can withstand the weather. It's not a hazard to animals, it's on a farm. I guess it depends on a very specific use case scenario, that the fact is you'd need to consider you'd have obviously functional and non-functional requirements for that particular device.* (Participant 7)

The importance of catering for all types of users was highlighted by Participant ten in the following statement:

> *A big thing for me would be for these devices or platforms, to accommodate people of all literacy levels … it should be so easy to pick up and so intuitive that I should be able to use it as well as my grandpa should be able to … different people have different needs for technology ... technology plug into your life in such a way that it meets your specific need.* (Participant 10)

The following themes were identified from the interview response analysis for the second question:

1. Device Useability – This theme focused on ensuring that the smart device is simple enough for the end user to operate. This theme can be linked back to Norman's design principle called: '*Signifier*', which guides the end user on how to utilise the object (D. A. Norman, 1998).
2. Device Configuration – This theme focused on ensuring that the device is designed in such a manner that an end user can easily configure and control the smart device. This theme can be linked back to Ben Shneiderman golden rule called: '*Support internal locus of control'*, which allows the user to easy control and manage the device(Shneiderman, 2004).
3. Device Interoperability – This theme focused on ensuring that the device can seamlessly integrate with different device manufacturers. This theme can be linked back to the research finding by Rowland et al. (2015), where an important design element to consider is interuseability. This element requires the user interface to be similar across different set of connected devices.
4. Cater for all literacy levels – This theme focused on ensuring that the device can cater for end users who might not have much technical knowledge. In sum, catering for all types of end users.
5. Identifying the use case for the smart device – This theme focused on identifying the existing problem and type of end user they are trying to solve the problem for. Understanding the use case is imperative for smart device build. This theme can be

linked back to research conducted by Woo & Lim (2015), where do-it-yourself (D.I.Y) smart home products were designed to solve existing issues faced in an end user's daily lives.

6. Understanding and meeting end user need. This theme can be linked back to the Quality of Experience (QoE) metric, which ensures that device design meet end users requirements (Fiedler et al., 2010).
7. User interaction method – This theme focused on different types of interaction methods which can be used by end users to interact with the smart device. This theme can be linked back to the research findings by Nazari Shirehjini & Semsar (2017), where it was highlighted that it is prominent to identify the type of interaction that will be used to interact with IoT devices.
8. Physical device build – This theme focused on the device hardware element and environment condition that needs to be considered. This theme can be linked back to the research finding by Perera et al. (2013), where IoT devices hardware requirements were discussed. As stated by Woo & Lim (2015), an IoT device integration should not disrupt existing home interior.
9. Environmental impact – This theme focused on the smart device usage impact on the environment. This theme can be linked back to research finding by Jensen et al. (2018), where smart home devices should assist in reducing energy consumption.

Table 24 provides a summary of the identified emerging theme within the participants' responses to the elements that need to be considered when building an IoT device. Frequency count was then used to identify the occurrence of each theme in the participants' response. Figure 11 displays the common words that occurred in the participants' responses. A word cloud generator was used to create the image.

Table 24: IoT Design Elements (Researcher's Analysis)

Theme	Count
Device useability	3
Device configuration	2
Device interoperability	3
Cater for all literacy levels	3
Identify the user case of the smart device	3
Understanding and meeting end user need	3
User-Interaction Method	3

Physical device build	2
Environmental impact	2

Figure 11: IoT Design Component - Word Cloud

4.3.5 Data Collection and Presentation

Data collection and presentation is the fourth section identified under the semi-structured interviews. This section focuses on collecting data related to the participants' thoughts on device usage data collection and the presentation of the usage data to the end users. Smart devices require data to fully operate, indeed, Ndubuaku and Okereafor (2015) state that data is like fuel for smart devices. Participants were requested to answer two questions related to data collection and presentation.

The first question under the data collection and presentation section that the participants were required to answer was:

"What are your thoughts on the IoT data collection from end users?" The purpose of collecting the data above was to understand and identify the components that are considered when collecting and processing device usage data. Participants were requested to explain how they felt about the data collection process and the measures that could be implemented to enhance the existing processes.

Five Participants mentioned that data collection is imperative for enhancing user experience of the smart device. Participant ten explains the benefits of data collection in the following statement:

> *I have two minds about it … if it [is] for the purpose of improving my experience, because again, I think these devices can only serve you better according to how much they know about you, right? When you plug in for the first time, your experience will be different from when you're 100 days in, because this is you're feeding it information about yourself, so they could just know you better.* (Participant 10)

While data collection is imperative for device functionality, a number of participants also highlighted the issue of data privacy, transparency and the types of data collected from the end user. Participant three addressed the data privacy and transparency issue:

> *You know, privacy is a huge thing, confidentiality, those are huge things when it comes to data collection … transparency as well, is a problem, because if I'm using tell me that I'm collecting your data, or can I please collect the data? … Then I'll be able to assist and say, okay, my data is going to be used for this, I'm uncomfortable with it or not, if I'm comfortable, then yes, if I'm not, then, you know, I don't consent as simple as that. So, the transparency for me is a huge issue and the fact that we even have talked about this in itself*. (Participant 3)

Educating end users about what the collected data will be used for is crucial. Smart devices placed in a personal home setting might be collecting data that is confidential and sensitive for the end user. Participant nine noted the lack of education in the following statement:

I don't think people understand what they're signing up for or giving away. I think a lot of people just accept it … I see Google, for example, is doing a lot of steps to try explain those to customers … and I don't really typically see that in like an IoT device, you know, when suddenly would ask for other information. And I think there needs to be better ways of communicating that to customers. (Participant 9)

Six themes were identified from the interview response analysis for the first question: Data collection required by device manufacturers to enhance user experience, data privacy, i.e., the confidentiality and sensitivity of the collected data; complete transparency required in data collection and usage; effectively educating end users about what the device usage data will be used for; end user comfort level is dependent on the type of data collected and what it is being used for; and data security, i.e., the storage, access and transfer of data. Frequency count was then used to identify the occurrence of each theme in the participants' responses. Table 25 provides a summary of the emerging themes identified from participants' responses to the thoughts on the IoT data collection component. Figure 12 displays the words that frequently appear in the participants' responses. A word cloud generator was used to create the image.

Table 25: IoT Data Collection (Researcher's Analysis)

Theme	Count
Data collection required by device manufacturers to enhance user experience.	5
Data privacy: Confidentiality and sensitivity of the collected data.	5
Complete transparency required in data collection and usage.	4
Effectively educating end users about what the device usage data will be used for.	3
End user comfort level is dependent on the type of data collected and what it is being used for.	3
Data security: storage, access and transfer of data.	3

Figure 12: IoT Data Collection - Word Cloud

The second question under the data collection and presentation section that the participants were required to answer was:

"The collected data by IoT device is presented back to user in a visualisation form, what key points should be considered when presenting of the data back to the end users?"

The purpose of collecting the data as relates the question above was to understand which elements are considered by participants when presenting device usage information back to the end user.

Five participants noted that the device usage information presented to the end user must be used to educate and assist in decision-making and provide recommendations to enhance their lives and device usage experiences. Participant seven speaks to the information visualisation purpose in the following statement:

> *The information on the visualisation is meant to be something enough to lead. Second to that is (sic) the insights that allow you to make informed decisions and be proactive. Either corrective measure or*

> *giving you insights that helps you benefit and significant changes, things that you would not have noticed before*. (Participant 7)

Participant nine mentioned that an IoT data collection report could be provided to the end user monthly, to display what types of data are being collected and instructions on how to prevent data from being collected if the end user is not comfortable with it.

The importance of selecting the best visualisation method was also mentioned by three participants because the wrong interpretation of the visualised data could lead to confusion and end users feeling overwhelmed. Participant eight highlights the importance of selecting the correct visualisation in the following statement:

> *I think is a necessary aspect of that, I think there needs to be considerable talk given in terms of that presentation. Especially if you're presenting information that is very easily misinterpreted and cause users to, it can have consequences*. (Participant 8)

Participant three also mentions the factor of knowing your audience and the selection of the correct visualisation method that caters for all types of users in the following statement:

> *Things that would need to be considered are choosing the right type of visualisation, for the data that you would like to do to display … telling a story through that data, you know, making it tangible, making it relatable to the person that you're, you're showing it to … data visualisations tend to be a bit complex. And users generally have to connect the dots, about visualisations … when it comes to dashboards, sometimes like, if you're not a data analyst … a dashboard is overwhelming … basically*

knowing your user and knowing your audience for this type of stuff.

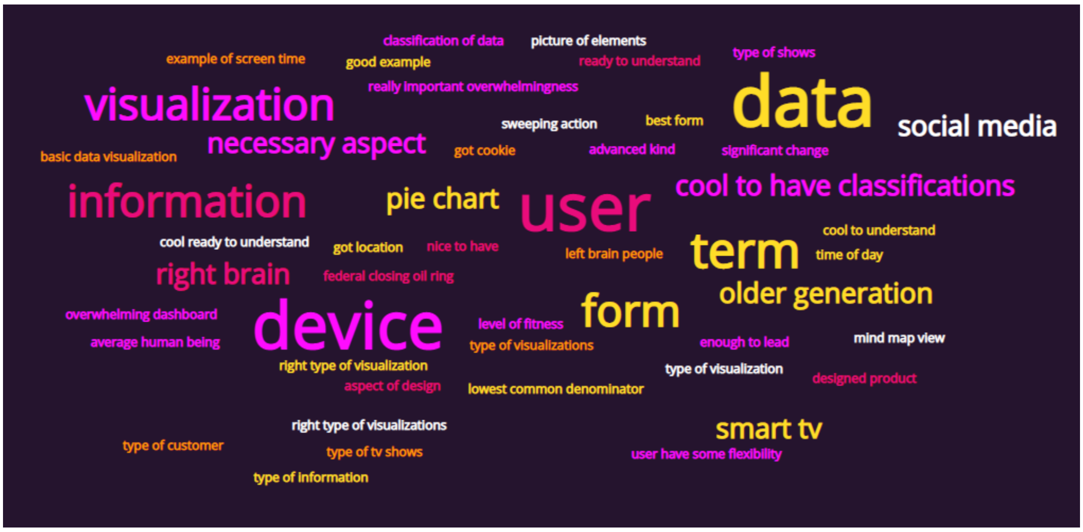
(Participant 3)

Five themes were identified from the analysis of the interview responses to the second question: presenting information and recommendation that educate users on the device usage, knowing your audience, providing valuable insight that assists in decision-making, selecting the right visualisation method that cater for all types of users and understanding what types of information are crucial to the end user. Frequency count was then used to identify the occurrence of each theme in the participants' responses. Table 26 provides a summary of the emerging themes identified from participants' responses to IoT data presentation. Figure 13 features the words that frequently occurred in the participants' responses. A word cloud generator was used to create the image.

Table 26: IoT Data Presentation (Researcher's Analysis)

Theme	Count
Presenting information and recommendation that educate users on device usage.	5
Knowing your audience. Example from the interview: "*I think it also depends on the type of customer. Like I said, most guys are just interested in user kind of stuff. It'd be cool if your IoT devices sent you like a monthly report that said, Hey, this is the staff we collected from you...*"	3
Providing valuable insight that assists in decision-making.	3
Selecting the right visualisation method that caters for all types of users.	3
Understanding what types of information are crucial to the end user. Example from the interview: "*But I think I would like for the device to sort of draw some intelligence out of it, you know, give me a bit of Intel behind it. If my medical aid is linked to how many steps I take a day, I think my smartwatch should be able to tell me somehow that you know, or discovery or whatever should be able to tell me that doing 10,000 steps a day, for three months will reduce your medical aid claims by this much.*"	2

Figure 13: IoT Data Presentation - Word Cloud



4.3.6 IoT Device Security

The last section identified through the semi-structured interviews was device security. This section focused on collecting data pertaining to the data security of smart device data. Participants were requested to provide their thoughts on what security elements could be implemented to enhance the user experience pertaining to the security of the device. The data above also assisted the researcher in understanding the participants' thoughts on the security element and what measures were currently being installed to protect the end user data and identity. The participants were requested to answer the following question: *"What are your thoughts related to the security and the data collection element?"*

Five participants mentioned that security is an important element when designing the IoT devices because they are connected to the internet and are vulnerable to external threats. Participant three highlights an end user's comfort level with sharing data with companies in the following statement:

> *And I guess that's what also make[s] users a bit apprehensive about sharing their data, especially with certain companies. Like security and has been transparent generally … Is this data that could compromise*

my wellbeing or is this data that does not have that much relevance in my life, I guess that's also another thing users would always people open to sharing the data, if they felt that it was safe. (Participant 3)

While device manufacturers require usage data for the device to fully reach its potential and function as expected, participants noted that manufacturers need to focus on capturing data that is essential and prevent gathering unnecessary data. Participant four explains the data collection process in the following statement:

If you use my data, so they tell you, the company and under the user and using my data ... I don't have a problem with you using my data but use it for me. And, and when you use it for somebody else, then make sure that it doesn't directly relate back to me. So, make sure that it's depersonalised … they need to be concerned that you are collecting this data and that you're processing the data and making sure that you're using it to deliver a service to me and not just collecting unnecessary information. (Participant 4)

An end user's comfort level with device usage depends on how secure and protected the device is. Participant ten explains the existing trust issue with data collecting in the following statement:

I have got a, like a blank, online profile that, you know, has no data about me … So I'll log into those apps, especially ones that have sensitive information, information with credentials that don't reveal anything about me … enjoy the content in such a way that the algorithm doesn't build a persona for me and even if it does, it, can't attach it or link it back to me because I want the private things and the sensitive *things about me to remain that way. And it's because of that trust issue*.

(Participant 10)

Six themes were identified from the analysis of the interview responses to the first question: An important element to consider when designing the device, the level of security controls (e.g., encryption) that needs to be implemented depends on the data sensitivity, end users will not be fully comfortable with using the device if the device is not secured, collected data should not disclose users' personal identities and location, users' concern level with sharing data depend on what type of data is collected, manufacturers should abstain from collecting data that they do not require and limiting access to the collected data at rest. Frequency count was then used to identify the occurrence of each theme in the participants' responses.

Table 27 provides a summary of the emerging themes identified from the participants' responses on IoT device security. Figure 14 highlights common words that occurred in the participants' responses. A word cloud generator was used to create the image.

Table 27: IoT Device Security (Researcher's Analysis)

Theme	Count
An important element to consider when designing the device. Example from interview: "*As a designer, make sure that your device, smartphone, or Smart TV is secured in such a way that you would not be exposing your users to any danger, whether they're on the internet or they're even offline. So I think security is one of the most important thing that we have to do, especially when it comes to protecting the users data*"	5
The level of security controls (e.g., encryption) that need to be implemented depends on the data sensitivity.	4
End users will not be fully comfortable with using the device if the device is not secured. Example from interview: "*If I was a user, I would definitely use a system that I'm quite confident that it's protected, that I know that my data will not be shared with any other person or there will not be a possibility of a hacker coming in, collect the data unlawfully and going use it somewhere else*"	3
Collected data should not disclose users' personal identities and location.	4
Users' concern levels with sharing data depend on what type of data is collected.	4
Manufacturers should abstain from collecting data that they do not require.	2
Limiting access to the collected data at rest.	3

Figure 14: IoT Device Security - Word Cloud

4.4 CONCLUSION

The preceding section provided an in-depth analysis of the semi-structured interview transcriptions. The semi-structured interview structure was divided into the following six sections: participants' demographic data, concept understanding, IoT device usage and design experience, data collection and presentation and, IoT device security. The participants were required to answer a total of nine questions as part of the interview. Based on the participants' responses, most of them had a fair understanding of the IoT and HCI concepts. Several participants noted that they had had a pleasant experience using IoT devices but there were few of the participants who noted that setting up the device was a struggle. Over time, participants learnt how to operate their IoT devices.

Most of the participants also agreed that Human–Computer Interaction is an important element to consider when designing an IoT device. Much of the focus was on catering for all literacy levels and ensuring that the useability requirements are met. The participants mentioned several design components which should be included when designing an IoT device. For the data collection element, participants asserted that the collected data should mainly be used to enhance their user experience. Data privacy and sensitivity were also noted by the participants. For the data presentation element, participants highlighted that the presented information and recommendations should educate users on their current device usage behaviour. Participants noted that device security is a crucial element which needs to be accounted for when designing an IoT device.

CHAPTER 5: CONTRIBUTION AND CONCLUSION

5.1 INTRODUCTION

The purpose of this research study was to identify the principles of HCI components in IoT devices. Participants who reside in South Africa were requested to complete a questionnaire that focused on understanding the current user experience of smart home devices. To further comprehend the inclusion of HCI components in the IoT design process, case study organisation employees were requested to participate in a semi-structured interview. The following research questions were answered as part of the study: What is the user motivation for purchasing an IoT device? What are users' concerns regarding data collection and privacy? How does information related to IoT device usage is being represented/returned to the end user? What are the challenges of IoT devices in relation to Human-Computer Interaction (HCI)? What components are considered for designing an IoT device?

In this section, the researcher will provide detailed insight that was derived from the collected data and past literature as well as a summary of the findings. This section also focused on describing the incorporation of the activity and cognitive load theory with the research findings. The study's limitations, contributions and future research requirements will be discussed in the concluding remarks.

5.2 SUMMARY OF FINDINGS

5.2.1 IoT Device Purchase Motivation

The South African IoT market has been predicted to grow at a 20.96% rate annually from 2020 to 2025 (IndustryARC, 2021). Smart homeowners are predicted to reach a total of three million users by the end of 2026 (Statista, 2022). To ensure the successful adoption of IoT devices, the device designer needs to consider the end user's wants and needs when building the devices. The purpose of the smart device is to enhance the quality of life (Marikyan et al., 2019) or solve an existing problem being faced by the end user. It is imperative to identify the most common reason that end users consider when purchasing a smart device instead of a traditional device. Understanding user motivation for using a system is crucial as it has a direct impact on the user experience (Beale & Peter, 2008).

In this research study, the researcher utilised the questionnaire method to identify the smart device details that are used in a household as well as the motivation for purchasing these devices. Past literature also assisted with identifying the adoption of smart devices. These adoption motivations include efficient energy management, financial savings, improved quality of life and improved healthcare within a home (Li et al., 2021). In research conducted by Schill et al. (2019), end users indeed indicated that smart home solutions are environmentally friendly.

This research study focused on smart home device consumers who reside in South Africa. Fifty-seven smart home device end users were requested to provide user experience data about smart home devices. From the collected data, the following information was derived: the most common type of smart home device used within the household environment was a smart television (TV) (68.42%). The second most common smart home device purchased by consumers was smart lights (8.77%). While various types of smart home devices are available on the market, Participants of a household are mostly interested in automating the entertainment objects within their households. Around 42.11% of the participants have had their smart devices for 0–2 years. While smart home devices have been available to consumers since the early 2000s (Taylor & Harper, 2003), the collected data revealed that the adoption of smart home devices by smart home consumers had only recently started since most of the participants have had their smart home devices for less than five years (82.77%).

Samsung (40.35%) was identified as the most common brand of smart home device. The ability to stream entertainment services like Netflix or YouTube (23%) was identified as the most common purchase reason by the end users. The other common reason for purchasing a device that smart home device users provided was an internet connection feature, the convenience features of the smart device, end users required a device upgrade and for the smart feature that included the device being connected wirelessly, device usage monitoring function, etc.

5.2.2 IoT Device Usage and Maintenance Experience

Understanding the user experience concerning smart device usage and maintenance is imperative for device designers to further understand the current challenges faced by end users. To address the sub-problem, the questionnaire and semi-structured interview participants were requested to provide detail on their current usage and maintenance experience with their devices. The slow rate of smart home ownership was highlighted in an article written by a South African digital news provider. Despite the prediction of growth in the smart home market, usage and implementation of IoT devices by consumers in South Africa are 23% less than for global consumers. The following issues were highlighted in the article: unreliable internet or consumer not having access to the internet, the trust in smart devices and the costs associated with automating a household (CBI Electric: low voltage, 2022).

For the questionnaire, fifty-seven participants were requested to provide their usage and maintenance details and for the interview, ten participants were requested to provide details on IoT device usage. The researcher reviewed the collected data and past literature to answer the question. The questionnaire included open- and closed-ended questions that were designed using the Likert scale.

The following information was derived from the collected data on the smart device usage experience and maintenance:

- Almost all participants (98.24%) found the initial setting up of smart home devices easy.
- Most of the participants (82.45%) agreed that the smart device that they had purchased met their expectations and needs. Around 15.79% of the participants were neutral about their expectations being met by the device.
- Almost all of the participants (94.74%) found the smart home device easy to use and maintain.
- While around 35% of the participants did not mention any challenges when using their smart home device, the rest of the participants had faced a number of challenges (65%). The participants highlighted these challenges as being device software upgrades, difficulties in navigating all the features on the smart device,

internet connectivity issues and that the initial setting up required coding and configuration skills. Despite the participants declaring that the initial set up of their smart home devices was easy in the first statement, a number of participants indeed struggled with setting up their smart home devices.

- The most common tool used by the participants to manage their smart devices was the smart device itself (54.39%). The second common type was a mobile application (31%). In a past study conducted by Koskela and Väänänen-Vainio-Mattila (2004), participants were interested in controlling and managing their smart home devices from a central place (e.g., mobile phones or personal computers). This study's results, therefore, align with previous studies.

During the semi-structured interviews, more than half of the participants (60%) revealed that they have had great experiences with no issues when using IoT devices. Some participants (30%) struggled with the initial set up but learnt how to operate the smart device over time. From the above information, it can be concluded that while the participants did find it easy to navigate and use the smart home devices, participants pointed out that there were challenges with a smart home device is placed inside a home. Setting up the device was specified as a challenge in both the questionnaire and semi-structured interviews. The first impression of using a product is crucial and IoT device designers must focus on simplifying the initial set-up of devices for all types of users.

5.2.3 IoT Device Design Components

When building IoT devices for end users to utilise, both technical and non-technical factors should be considered (Vermesan & Bacquet, 2017). The HCI component in the IoT device design-build phase focuses on ensuring that the device is easy to use by the end user and meets their expectations. In a study conducted by Beale and Peter, (2008), it was noted that designers must incorporate emotion into their systems and products. Human emotions are dependent on their interaction with and the functionality of the final product.

To answer the research question, ten organisational employees were requested to provide their thoughts on incorporating HCI in IoT device design-build and what elements are important when building an IoT device. At the beginning of the interview, the researcher requested participants to provide their understanding of the HCI and IoT concepts.

All participants had a fair understanding of the IoT and HCI components. Around 60% of the participants had previous experience in designing IoT physical devices or the software used to manage the device while the remaining 40% of the participants have worked on integration technical solutions and working with a new set of technologies. From reviewing past literature and the participants' responses, the following information was derived from the researcher:

- Past literature has highlighted the integration of the Norman design concept while building smart devices and the importance of designing a product around user needs and interests (Urquhart & Rodden, 2017). Interuseability between different smart devices also needs to be considered by the design team (Rowland et al., 2015). Most of the participants (70%) consider HCI an important element that needs to be considered when designing IoT devices. The designer should take a user-centric design approach while building these devices since the end user will be responsible for maintaining and operating the device. The smart devices should be designed in a manner that caters to technical and non-technical end users. The research findings align with what has been noted in the past literature.

- Based on the participants' responses, the following factors need to be considered when building an IoT device: the device must be able to integrate and function with other smart devices, the device is easy to use and seamlessly integrate with a household, the device can be used by users with varying literacy levels, an efficient user interaction method must be identified, the physical building of the device, the impact that the device will have on the environment and addressing end-user needs and wants. It is imperative to ensure that the smart device is either addressing a current problem faced by the end user or enhancing their quality of life.

5.2.4 IoT Device Data Collection and Presentation

The data collection process is an important and required function within an IoT device. For the device to fully reach its potential and operate, data is required by the device to build context and enhance user experience (Ndubuaku & Okereafor, 2015). As part of the semi-structured interview, the organisational employees were required to provide their thoughts on the IoT data collection element. Half of the participants (50%) agreed that device manufacturers require data to enhance user experience. Data privacy and the sensitivity of the data need to be identified and considered when collecting the data as the participants expressed that their (end-user) comfort level depends on what type of data is being collected. Educating end users about the data collection process is an important factor that needs to be provided for when communicating with end users. One of the participants suggested using blockchain technology for data transparency. Device manufacturers need to be fully transparent about what type data of is being collected and what it will be used for.

The importance of data flow visibility and usage transparency has previously been discussed in an article by Schraefel et al. (2017). As part of the questionnaire, fifty-seven participants were required to provide their experiences with smart device data collection, its presentation and how they could access the data. The statement was designed using the Likert scale. The following information was derived from analysing the collected data:

- More than 80% of the participants were aware that the smart home device is collecting data. Around 14% were unaware that the device was collecting data. The participants who were unaware of the data collection element had smart televisions (TVs), smart lights and air fryers installed in their homes. Most of these participants had the smart home device for less than three years.
- Less than 50% of the participants had access to their smart device's usage data and 33.33% of the participants did not have access to viewing device usage data. The majority of the participants who did not have access to device usage data owned smart televisions (TVs), smart air fryers and smart lights.
- The most common tool that is being used to view the usage data detail was the smart device itself (29.82%) and the second common tool used by the end users was a mobile application (24.56%).
- Around 41.11% of the participants were neutral about the presented device data being useful and easy to comprehend. A number of the participants (17.55%) disagreed that the collected data was useful and easy to comprehend.

From the above information it can be noted that there are smart device end users who aren't knowledgeable about data collection processes and access to the collected data. For end users to benefit from the collected data, they need to have access to it and the data needs to be presented in a format that is easy to comprehend by all types of users. Previous research has highlighted the usefulness of a selected visualisation method (Tory & Moller, 2004) as well as of converting raw data into meaningful information that is easy for people to understand (Nuamah & Seong, 2017). Semantic computing can be utilised by IoT device designers to generate meaning from the collected IoT device data, it can also assist with resolving the heterogeneity issue (Sheu, 2008; Sheth, 2016).

The semi-structured interview participants were also requested to provide a list of elements that they consider when displaying collected usage data back to end the user. The requirement to present information in a manner that assists with educating the end-user on device usage and decision-making was highlighted. It is crucial to identify the audience of the visualisation as well as to choose the most effective visualisation type that would cater to all types of users.

5.2.5 IoT Device Security and Privacy Concerns

An IoT device is required to be connected to a network to constantly collect and share data with other smart devices for it to operate within an environment. As the devices are exposed on the internet, it creates potential threats of cyber and denial of service attacks (Singh & Singh, 2015). While the implementation of IoT devices has improved and automated daily tasks in end users' lives, it has also increased security and privacy challenges. Device manufacturers are required to implement the appropriate measures to address security and privacy challenges (Tawalbeh et al., 2020). During the semi-structured interviews, participants were requested to provide their thoughts on IoT device privacy. The security element was highlighted as an important factor by the participants and the following measures were recommended to enhance device security: the collected usage data should not disclose end users' identities or exact locations, the level of security controls that needs to be implemented on the usage data depends on the data sensitivity, the access to data at rest should be effectively managed and limited to required personnel only and device manufacturers should abstain from collecting unnecessary data. End users' comfort levels with data collection is based on what type of data is being collected. For an end user to fully trust the smart device, it needs to be secured (Coughlan et al., 2012).

In research conducted by Psychoula et al. (2018), end-user privacy concerns for IoT devices were discussed. End users highlighted that they were concerned with who had access to collected data, smart devices not operating as expected and the devices being hacked by cyber hackers. Participants were required to provide their thoughts on IoT device security in the questionnaire. More than 50% of the participants did not have security concerns related to smart home device usage. The majority of the participants who did not have security concerns purchased smart home devices from popular brands like Samsung, Google, LG, Apple, etc. The findings link back to research conducted by Zheng et al. (2018) in which the participants trusted the device manufacturer concerning the privacy aspect. Around 22% agreed that they did have security concerns related to smart home device usage. The participants raised the following concerns: login credentials being compromised, device data collection and who has access to the data, usage data being sold to third parties and the device being hacked. The participants who had security concerns owned smart televisions (TVs), smart speakers, smart air fryers, smart blinds or a complete smart home set-up within their homes.

5.3 PRINCIPLES OF HUMAN–COMPUTER INTERFACE IN IOT DEVICES

The purpose of the research study was to understand the current user experience of smart home devices installed within households and the importance of the HCI element when designing IoT devices for end users. The study aimed to assist IoT device manufacturers and HCI designers to identify and address the current challenges and concerns raised by end users. The interview assisted with providing insights into the elements considered by Information Technology (IT) experts when designing an IoT device. The following social theory was utilised to analyse the research findings: cognitive load theory. To further understand the phenomena in depth, two data collection methods were used to gather data. Fifty-seven participants who reside in South Africa and owned a smart home device were requested to participate. The study required ten employees from the case study organisation to participate, to understand the current design process of IoT device build.

The theoretical framework used to analyse the research findings was the cognitive load theory. Cognitive load theory focuses on the amount of working and long memory available for an end user to perform a task or solve a problem. Within the HCI community, the focus has been on reducing the user's cognitive load by designing effective technology interfaces that decrease the extraneous cognitive load, which can then assist the end user to shift their attention to the main task (Oviatt, 2006). As highlighted by Al Siyabi and Al Minje (2021) , cognitive load theory was initially used for new education material implementation but it is moving towards the HCI space for web-based learning. An extraneous cognitive load is generated when the presented information may not be suitable during the learning phase. When introducing a new technology product, end users are required to learn how to use the interface and over time learn how the product operates.

For addressing an aspect of the study, the researcher requested smart home device owners to describe their experiences with setting up and using their smart devices. The purpose was to understand the amount of effort and mental power that was required to use smart home devices. Almost all of the participants indicated that the smart device was easy to install and set up in their homes. The usage and management of smart home devices were marked as easy by the majority of the participants. Despite the installation and usage of the smart device being marked as an easy task, several participants raised challenges with using the smart home devices. The challenges (Refer to section 4.2.2.) that can be linked to cognitive load theory are the following:

1. Participants found the initial setting up challenging because the instructions provided by the device manufacturer were insufficient or the smart device was not available in South Africa. Setting up and installing may increase the cognitive load on the user's memory. Working memory is limited and therefore, an increase in cognitive load can lead to a negative experience with the device usage.
2. A participant had to master a new skill to enable them to set up the smart home device. This has an impact on cognitive load since the end users were unable to successfully use the device based on the (then) current information available to them.

3. Remembering the login credentials was also highlighted as a factor since the participants were required to retrieve information from long-term memory to use their devices.
4. The number of features available on the device overwhelmed the end user.This challenge may then lead to additional cognitive resources being required to navigate the smart device. This challenge, therefore, has an impact on the 'spilt-attention principle' which focuses on reducing the amount of information required to use the device.

IoT devices collect usage data and present the data back to end users for various reasons. The researcher requested the participants' experiences with viewing usage data for their smart home devices. The participants had mixed responses and less than half of the participants were neutral about the available data being useful and easy to comprehend (Refer to section 4.2.3.). Around 28% of the participants disagreed with the provided statement. Participants did not find the presented device usage information useful and easy to comprehend. Therefore, a lack of comprehension might require end users to make use of additional cognitive resources to process the presented data.

Semi-structured interview participants mentioned that the device usage information must be presented using the correct visualisation that caters to different literacy levels. The device usage information should focus on telling a story and educating the user in a simplified manner. Participants referred to Google with respect to educating users on what types of data will be collected and used. Accordingly, the research findings align with cognitive load theory.

5.4 REFLECTION ON CONTRIBUTION

In this section, the researcher discusses the research findings that can be added to the existing body of knowledge of the HCI field of study, how HCI practitioners can utilise Norman's design principles when building IoT devices for end users and lastly, the researcher will share their personal reflections on this research study.

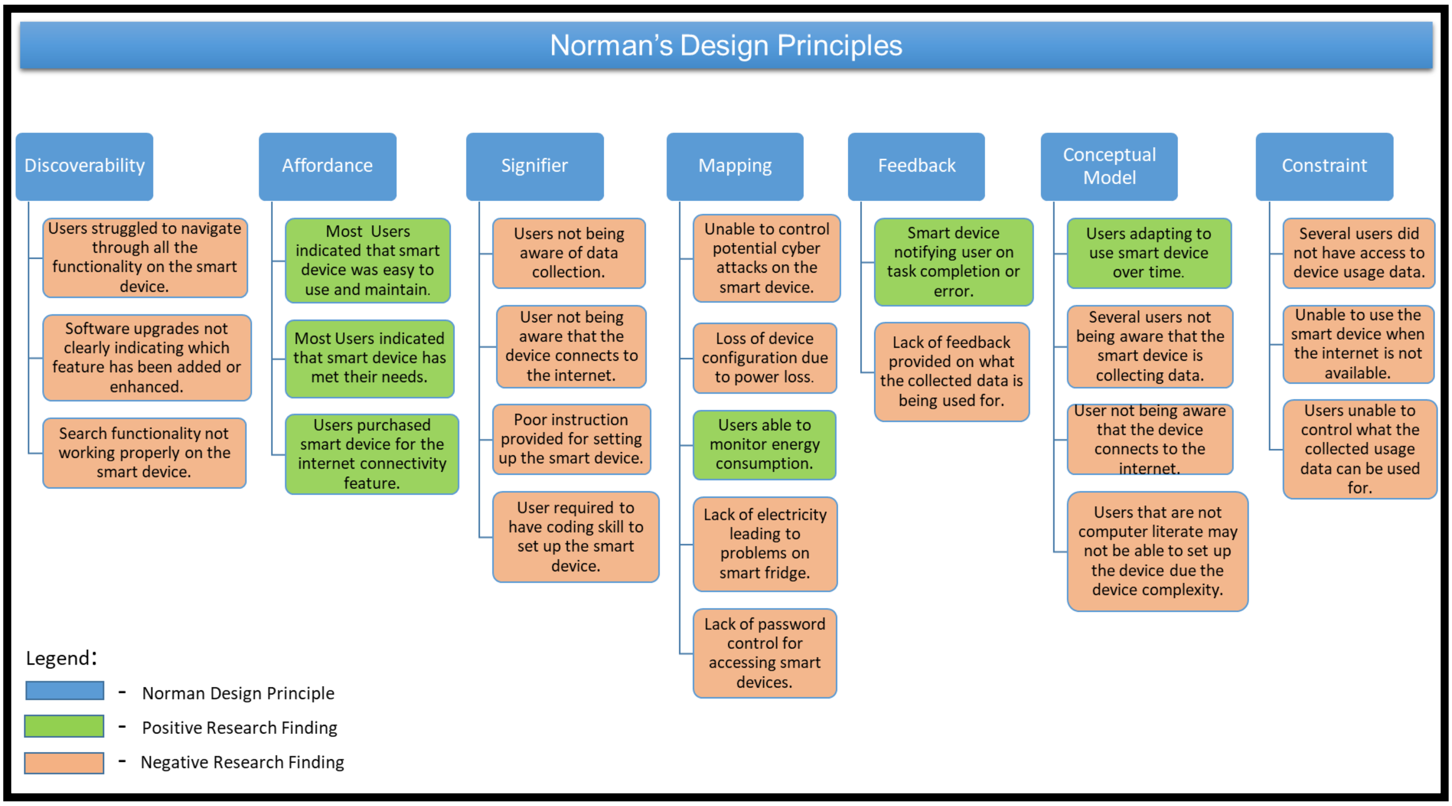
5.4.1 Body of knowledge

Chapter 2 covered the existing literature available on HCI applications when designing an IoT device. This research study assisted in identifying the end user’s motive for utilising smart devices instead of traditional devices. HCI practitioners can use the identified purchase motive to understand end users' needs and wants. Based on the research finding, it can be noted that there are several IoT device usage challenges and concerns that need to be addressed by HCI designers to ensure that end users trust smart devices. HCI designers need to look for intuitive ways of addressing end-user concerns and challenges to ensure the successful implementation of smart devices in future. This study also assisted in indicating the crucial design components when building a smart home device. Much of the focus was on catering for end users with all levels of literacy and ensuring that only required usage data is collected to enhance user experience.

5.4.2 Practical application

Norman’s eight design principles (Norman, 1998) were used to link the research findings results. The positive and negative research findings on using IoT devices were mapped out in Figure 15. The colour blue highlights Norman’s design principles, the colour green indicates postive research findings and the colour red indicates negative research findings. IoT device designers should take the principles laid out below into account when designing smart devices for end users. For smart devices to be successfully implemented in any environment, it needs to meet useability requirements. A detailed explanation of all Norman’s design principles is provided in Chapter 2.

Figure 15: Research Finding Mapping to Norman's Design Principles



5.4.3 Personal reflection

I embarked on this research journey to fully understand the current user experience with smart home devices in South Africa and what components were being considered by information technology (IT) experts when designing an IoT device for use by end users. Being in the technology industry, I have also been curious about the implementation of the IoT for different use cases and how it has been enhancing people's lives. By embarking on this journey, I have come to thoroughly understand the importance of building smart devices around end users' needs, as they become the sole managers and administrators of these smart devices. In talking to the research participants during the semi-structured interviews, I understood that design gaps still exist with the IoT and these need to be resolved by the device designers. The end user should not be treated as an external component of the design process.

5.5 FUTURE RESEARCH

This research study addressed two aspects. The first aspect focused on understanding the current user experience of IoT implementation within South African households. While the adoption of smart home devices is steadily growing, the need to address end-user concerns and struggles is prevalent. Smart television (TV) was identified as the most common smart device installed within a home. Despite the end users finding the installation and management of smart devices easy, several device usage challenges and security concerns were highlighted and addressed in this research. The second aspect of the research focused on incorporating HCI when building IoT devices and identifying elements that are crucial to consider when designing IoT devices. The findings were summarised and linked to cognitive load theory. Further research could be conducted to understand the implementation of IoT devices within different environments such as smart cities or industries within South Africa. While this research focused on the current implementation of smart home devices within South Africa, the future researcher could delve into understanding why South African households have not implemented smart home devices. This, in turn, could assist with identifying end users' resistance to implementing smart home devices.

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7 APPENDIX A – ETHICAL CLEARANCE LETTER

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

29 June 2022

Reference number: EBIT/18/2022

Miss S Waqar
Department: Informatics
University of Pretoria
Pretoria
0083

Dear Miss S Waqar,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Approval is granted for the application with reference number that appears above.

1. This means that the research project entitled "Identifying Principles of Human Computer Interaction in IoT Devices: A South African Context" has been approved as submitted. It is important to note what approval implies. This is expanded on in the points that follow.
2. This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Research Ethics Committee.
3. If action is taken beyond the approved application, approval is withdrawn automatically.
4. According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.
5. The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof K.-Y. Chan
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

8 APPENDIX B – SUPERVISOR LETTER OF APPROVAL

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering,
Built Environment and Information Technology

1956 – 2016
60 years of Engineering Education

14 November 2022

To whom it may concern

Research proposal approved: Ms S Waqar

Ms Waqar (Student nr. 16185952) is registered for a MCom INF at the University of Pretoria.

Supervisor : Prof Hanlie Smuts

Research topic is: Identifying principles of human computer interaction in IoT Devices: A South African Context

I herewith confirm that Ms Waqar research proposal has been approved. She may continue with the planning of her data collection, as well as her ethics application.

Kindest regards

Prof MC Matthee
Postgraduate Coordinator: Informatics
012 420 6321

9 APPENDIX C – QUESTIONNAIRE

Informed Consent Form

1. Project information

1.1 Title of research project: Identifying principles of human computer interaction in IoT Devices : A South African Context

1.2 Researcher details:

Name – Saman Waqar
Email : u16185952@tuks.co.za
Cell : 0742332684
Department : Informatics

1.3 Research study description.

Project Description:

The purpose of the project is to study the principles of Human Computer Interaction (HCI) in smart home devices. The study will be conducted in South Africa and the participant required for the study are consumer's that possess a smart home device and Skilled experts that will provide feedback on what components are important in building an IoT device. The smart home device can be but not limited to the following type; Smart TV , Smart Camera , Smart Cooking Appliances, Smart Lighting , Smart Sensors, Smart Speakers and Smart plugs etc.

Project Objectives:

The main objective of the project is to study the benefits and challenges of using a smart home device , security and privacy concern related to the smart device and accessing the information generated by the smart device.

Participants Requirements:

The participant is required to do the following:

- The survey can be completed during anytime that the participant is comfortable with.
- Participant must volunteer to participate in the study.
- Complete the consent form provided by the researcher in the survey link.
- Complete the survey on the link shared by the researcher. Please note that the questions in the survey are related to usage of the smart home device. The research will be carried with integrity and maintain required confidentiality.
- Notify the researcher that the survey has been completed.

Risk Involved with Participating in the Study:
There are no risk identified for participating in the study.

I herby voluntarily grant grant my permission for participation in the project as explained to me by Saman Waqar. The nature, objective, possible safety and health implications have been explained to me and I understand them. I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication. *

◯ Yes

◯ No

Smart Device Information

What type of Smart home device do you have? *

- ◯ Smart TV
- ◯ Smart Refrigerator
- ◯ Smart Lights
- ◯ Smart Camera
- ◯ Smart Speaker
- ◯ Smart Sensors
- ◯ Smart Plugs
- ◯ Smart Lock
- ◯ Other: ______________________

How long do you have the Smart home device for? *

- ◯ 0 - 2 years
- ◯ 2- 5 years
- ◯ 5 - 7 years
- ◯ 7 years +

What Brand is the Smart Home Device? *

- ◯ Phillips Hue
- ◯ Amazon
- ◯ Arlo
- ◯ Eve Energy
- ◯ Google
- ◯ Nest Learning Thermostat
- ◯ August
- ◯ Other: ______________________

Why did you purchase the smart home device? *

N/A

Back Next Clear form

Smart Device Usage and Maintenance

The smart device was easy to set up and install. *

- ○ Strongly Agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly Disagree

The smart home device met my expectation and needs *

- ○ Strongly Agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly Disagree

The smart home device is easy to use and maintain. *

- ○ Strongly Agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly Disagree

Please specify any challenges faced with using the smart home device. *

Your answer

How do you maintain and operate the smart home device? *

- ◯ Via a Mobile Application
- ◯ Via an Online Website
- ◯ Via the Smart home device (e.g. Button built on the smart home device)
- ◯ Other: ____

Back | Next | Clear form

Smart Device Data Collection

I am aware that my smart device collects usage data. *

- ◯ Strongly Agree
- ◯ Agree
- ◯ Neutral
- ◯ Disgaree
- ◯ Strongly Disagree

I can access my smart home device usage data *

- ◯ Strongly Agree
- ◯ Agree
- ◯ Neutral
- ◯ Disgaree
- ◯ Strongly Disagree

How do you access the device usage data? *

- ◯ Via Mobile Application
- ◯ Via an Online Webiste
- ◯ Via the device (e.g. Screen built up on device displaying usage details)
- ◯ Not Applicable as I do not have access to the device usage data.

The device usage data is useful and easy to comprehend. *

- ◯ Strongly Agree
- ◯ Agree
- ◯ Neutral
- ◯ Disgaree
- ◯ Strongly Disagree

Back Next Clear form

Smart Device Security

I have security related concerns with using the smart home device *

- ◯ Strongly Agree
- ◯ Agree
- ◯ Neutral
- ◯ Disgaree
- ◯ Strongly Disagree

Please specify the security concerns related to the smart home device. *

Your answer

Back Next Clear form

10 APPENDIX D – SEMI-STRUCTURED INTERVIEW

Informed consent form

1. Project information

    1.1 Title of research project: Identifying principles of human computer interaction in IoT Devices : A South African Context

    1.2 Researcher details:

    - Name – Saman Waqar
    - Email : u16185952@tuks.co.za
    - Cell : 0742332684
    - Department : Informatics

    1.3 Research study description.

    - Project Description: The purpose of the project is to study the principles of Human Computer Interaction (HCI) in smart home devices. The study will be conducted in South Africa and the participant required for the study are consumer's that possess a smart home device and Skilled experts that will provide feedback on what components are important in building an IoT device. The smart home device can be but not limited to the following type; Smart TV , Smart Camera , Smart Cooking Appliances, Smart Lighting , Smart Sensors, Smart Speakers and Smart plugs etc.
    - Project Objectives: The main objective of the project is to study the benefits and challenges of using a smart home device , security and privacy concern related to the smart device and accessing the information generated by the smart device.
    - Participants Requirements: The skilled expert participant is required to do the following:
        - Volunteer to participate in the study.
        - Each semi structured interview is planned to take around 30 – 45 minutes.

- The semi structured interview will be held online on Google meet.
- The link for the meeting will be shared in a mail and the participant is required to join the meeting via the link.
- Complete the consent form provided by the researcher in the meeting invite mail. The form needs to be completed before the interview begins.
- The semi structured interview will be recorded online using the record tool on Google meet.
- Please note that the participants personal data will not be included in the research finding.
- Once the semi structured interview is concluded , the researcher will close off the interview with the vote of thanks.

- Risk Involved with Participating in the Study – There are no risk identified for participating in the study.

2. Informed consent

2.1 I, ______________________ hereby voluntarily grant my permission for participation in the project as explained to me by Saman Waqar.

2.2 The nature, objective, possible safety and health implications have been explained to me and I understand them.

2.3 I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication.

2.4 Upon signature of this form, the participant will be provided with a copy.

Signed: ____________________ Date: ____________

Witness: ____________________ Date: ____________

Researcher: ____________________ Date: ____________

Interview Template

Candidate Name		Conducted By:		
Interview Date		Interview Start Time		
Position Title		Interview End Time		
Qualifications		Years of experience?		
Question Number	Question		Candidate Response	
Question 1	How would you define IoT?	Answer 1		
Question 2	What is your understanding of the HCI concept?	Answer 2		
Question 3	Explain your experience with regards to usage of an IoT device.	Answer 3		
Question 4	What is your experience in relation to designing of an IoT device?	Answer 4		
Question 5	What are your thoughts on incorporating the human computer interaction component while designing an IoT device?	Answer 5		
Question 6	What are some of the elements you will consider when building an IoT device for end users?	Answer 6		
Question 7	What are your thoughts on the IoT data collection from end users?	Answer 7		
Question 8	The collected data by IoT device is presented back to user in a visualization form, what key points should be considered when presenting of the data back to the end users?	Answer 8		
Question 9	•What are your thoughts related to security and data collection element?	Answer 9		

11 APPENDIX E – RESEARCH TITLE APPROVAL LETTER

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Economic and Management Sciences
Student Administration

Our ref: 16185952
Contact person: Miss Lerato Krappie
Tel: +27 012420 5387
E-mail: lerato.krappie@up.ac.za

02 December 2022

Dear Ms Waqar,

APPROVAL OF TITLE REGISTRATION

I have a pleasure in informing you that the following title registration has been approved.

> ***Identifying principles of human computer interaction in IoT devices: a South African context***

Your enrolment as a student must be renewed annually until you have complied with all the requirements for the degree, preferably during the official period of enrolment but before **28 February**. You will only be entitled to the guidance of your supervisor if annual proof of registration can be submitted.

Yours sincerely,

For: Prof Chitiga-Mabugu
Dean Faculty of Economic and Management Sciences

12 APPENDIX F – LANGUAGE EDITITING CERTIFICATE

Certificate of Editing

MCom in Informatics

IDENTIFYING PRINCIPLES OF HUMAN–COMPUTER INTERFACE IN IOT DEVICES: A SOUTH AFRICAN CONTEXT

by

Saman Waqar

Edited for English language usage

Lorinda Gerber
29th of November 2022

Professional EDITORS Guild

+27 72 125 9475
loredit.ele80@gmail.com

13 APPENDIX G – LANGUAGE EDITOR MEMBERSHIP DETAIL

Professional EDITORS Guild

Lorinda Gerber
Associate Member

Membership number: GER003
Membership year: March 2022 to February 2023

072 125 9475
loredit.ele80@gmail.com

www.editors.org.za