Universal Design in Automobiles: an investigation into simulators for differently abled drivers.

by

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Thesis submitted in fulfilment of the requirements for the degree

Master of Technology: Industrial Design

in the Faculty of Informatics and Design

at the Cape Peninsula University of Technology

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Cape Town
September 2016

DECLARATION

I, Gerhardus Johannes Coetzee, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

Simulators are used for many different purposes, among them physical rehabilitation and the training of differently abled learner-drivers. In South Africa, however, the extent of the latter type of simulators is limited to paraplegic learner-drivers only. The reason is that locally sourcing the necessary equipment to adapt commercial simulators for the training of differently abled learner-drivers presents a problem.

The concept of Universal Design stipulates that as many individuals as possible should be able to use a particular product. Consequently, a simulator for differently abled learner-drivers should accommodate as many such persons as possible. However, applying Universal Design in the area of design researched for the present dissertation adds further complexity due to the unique nature of the physical limitations experienced by individuals. A differently abled driver puts an extreme constraint on the design of a product - and becomes a limiting user.

Nevertheless, this dissertation adopts a Universal Design approach to investigate the possibility of designing such a simulator in South Africa, as well as its viability. A limiting user was included in the research to represent the bigger differently abled community. Field research was carried out by implementing a Participatory Design process. Furthermore, a team was selected according to a Meta-Design mind-set, including professionals from engineering, clinical psychology and occupational therapy. The leader and researcher was an industrial designer.

Several key themes emerged and were observed during the research process. These include the limiting user's approach to and experience of participatory design, the possibility of accommodating a limiting user through a modular design approach as part of the Universal Design framework, as well as the impact which attitudes of the various members of the meta-team, as well as of the limiting user, had on the entire research, design and construction process. The focus on a limiting user and a modular design approach allowed for the creation of a simulator platform that could be used for a variety of differently abled drivers. This was achieved by re-imagining the adaptive controls used in the simulator.

This study presents a simulator built according to Universal Design criteria and able to accommodate differently abled drivers who fall into the category of limiting users. The research process yielded a novel adaptation of the case study method: namely, a more specific Universal Design Case Study (UDCS).

Keywords: Universal Design, Meta Design, Participatory Design, Case Study, Adaptive Aid, Disabled, Limiting User.

ACKNOWLEDGEMENTS

I wish to thank:

- Vikki Du Preez, for guiding me through this dissertation.
- Professor M'Rithaa, M.K, for introducing me to the world of Universal Design
- Professor Oscar Philander, for providing me with the facilities to complete the practical part of this study.
- My Wife, for enduring the long working hours.
- My Father for helping me acknowledge the need to design for all.

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GLOSSARY

Terms/Acronyms/Abbreviations	Definition/Explanation
Accessible Design	Design focused on the principles of extending standard design to people with some form of performance limitation to maximise the number of potential customers who can readily use a product, building or service (ISO, 2001:2).
Activities of Daily Living (ADLs)	Where there are restrictions in activities of daily life: e.g. washing, dressing, eating, mobility (Vignon, 2002).
Adaptronics	An interdisciplinary technology for optimisation of structure systems (Lorenz, 2013).
Arthritis	Inflammation of a joint that may lead to changes in the joint's structure, causing pain and swelling (Saunders, 2003).
Assistive Technologies	Technology used by individuals with disabilities in order to perform functions that might otherwise be difficult or impossible (AccessIT, 2012).
Barrier-free Design	Design that seeks to eliminate physical barriers to people with disabilities; often used synonymously with physical "Accessibility" in built environments (Mugendi Kanampui, 2010).
Bilateral PFFD	A rare, non-hereditary, birth defect that affects the pelvis, particularly the hip bone and the proximal femur. The disorder may affect one side or both, with the hip being deformed and the leg shortened (Nicky's Drive, 2010; Farlex, 2012b).
Case Study	A research method in which the research approach is concentrated qualitative rather than quantitative research. (Thomas, 2011).
Disability	Defined as a "difficulty in functioning at the body, person, or societal levels, in one or more life domains, as experienced by an individual with a health condition in interaction with contextual factors" (Tuomilehto & Wareham, 2006:1220).
Design for Disability	Design philosophy and practice that specifically seeks to address the needs of people with disability (Mugendi Kanampui, 2010).

Driver	A person who drives a vehicle
Differently abled Driver	A person who drives a vehicle while having difficulty in functioning at the body, person, or societal levels, in one or more life domains, as experienced by an individual with a health condition (Thomas, 2011).
Enabling	A response that identifies what a person's need is in order to achieve a desired level of participation (M'Rithaa, 2009).
Extra-Ordinary Ergonomics	Design criteria responsive to physical, mental and sensory characteristics of human users; takes into account the needs of people with disabilities, as well as those experiencing the effects of natural processes such as ageing and pregnancy (Kroemer, 2006).
Instrumental Activities of Daily Living (IADL)	IADL are activities that people engage in once they have taken care of themselves. These activities enable people to live independently(Weston, 2009).
Impairment	When defined as a physical impairment it relates to any *"interactions affecting the body"* (Tuomilehto & Wareham, 2006:1220).
Independent Living	Living arrangement maximising independence of a person. (The Free Dictionary, 2003).
Limiting User	A member of the user population who, because of his or her physical characteristics, imposes the most severe constraint on the design of a product (Pheasant & Haslegrave, 2006:27).
Linear Actuator	An actuator that directs force in a straight line. A rotational force is converted into a linear force (Tooling University, 2013).
Mobility	Described as the "ability to move or be moved freely and easily" (Oxford Dictionaries, 2010).
Multiple Sclerosis (MS)	A chronic autoimmune disorder: affecting movement, sensation and bodily functions. It is caused by destruction of the myelin insulation covering nerve fibres (neurons) in the central nervous system (brain and spinal cord) (Kraft, 2012).
OEM	Original equipment manufacturer
Phocomelia	Congenital absence of the proximal portion of a limb or limbs, the distal parts being attached to

	the trunk by a small, irregularly shaped bone (Farlex, 2012a).
Simulator	A machine used to create an augmented reality of a real life environment or experience, such as driving. (Oxford Dictionaries, 2014).
Steer-by-Wire	A system that is developed to replace the physical connection between the steering wheel and the wheels of a car by using electric motors (Kader, 2006:3).
Universal Design (UD)	Suggesting that all elements and spaces be accessible and usable by all people to the greatest extent possible. This is carried out in all aspects of design through thoughtful planning with the focus on accessibility (Design, 1998:3).

1 CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Introduction

This chapter gives a broad background concerning the research topic. The introduction to the research explores the origin of universal design in an international context, after which the design challenge within a South African context is explored. Design concepts relating to universal design, such as accessible design, barrier free design, design-for-all as well as design for disability. As universal design has an impact on some instrumental activities of daily living - for instance, mode of transport - personal transport was found to stand out as particularly problematic, due to limited accessibility in the South African context. Thus personal transport in South Africa is explored as a focus area which has a direct impact on differently abled commuters, followed by findings of the physically differently abled statistics for South Africa. A case study approach is introduced as a research methodology and meta-design, along with participatory design, as a theoretical mind-set.

1.2 Universal Design: A brief Contextual Overview

Universal Design originated from the changing demographics of the 20th century. The average lifespan of humans was 47 years, and most people with chronic illnesses lived in nursing conditions. People are living longer today; the average lifespan has increased to 76 years (The Denver Post, 1998). Eighty percent of the US population lives past the age of 65, and the US Census Bureau estimates an annual growth of 40 million within 14 years (Jones & Stanford, 1996). In 2013, the life expectancy rose to the age of 78.8; thus the elderly population has grown since 1998 (Jiaquan Xu, M.D., Sherry, L., Murphy, B.S., Kenneth, D., Kochanek, M.A. & Brigham A. Bastian, 2016).

In addition to the age increase, more people are living with disability. World Wars I and II created a vast number of veterans with disabilities. However, the advances in medicine enable these people to survive under previously fatal conditions (McNeil, 1997). It is estimated in the US that among the age group of 6 years and over, 8.6 million individuals have had some form of challenge with one or more activities of daily living (ADLs) (McNeil, 1997).

Compared to the US Statistics the South African population is estimated at between 46.9 million (Stats SA, 2005a:8) and 48.3 million (Population Reference Bureau, 2008:14) and is projected to reach 51.5 million by the year 2025 and 54.8 million by 2050 - an estimated growth rate of 13% by 2050 (Population Reference Bureau, 2008:14). These demographic changes may result in a population that is older and more disabled than prior to the 21st century.

As people age, challenges arise with respect to activities of daily living (ADLs), as well as with instrumental activities of daily living (IADLs) (Weston, 2009). According to Weston, ADLs involve caring for or moving one's body, activities such as walking, bathing, dressing, toileting, brushing teeth and eating. IADLs, on the other hand, are activities that people engage in once they have taken care of themselves. These tasks enable people to live independently. Many people can, however, still experience an independent life while requiring help with one of these tasks: cooking, driving, using the telephone or computer, shopping, keeping track of finances, and managing medication (Weston, 2009). Lawton and Brody (1996) classify the IADL task of driving under mode of transport. Mode of transport involves independent travel on public transport or using personal transport, arranging travel via a taxi, travelling on public transport when accompanied by another, as well as travelling by taxi with the assistance of another (Lawton & Brody, 1996).

Focusing on disabled people, professions became aware of the exclusions of disabled persons' needs, and attempted to address the lack of their participation in mainstream activities (Buden, 2002). Design is recognised as a powerful tool that could be used to address the problem of product discrimination by exclusion. Edeholt (2004, cited in Jönsson & Certec, 2006b:145) states that "design has direction [and] at its core, it deals with how things should be, what they should become, rather than how they are". A designer should aspire to be part of the solution; good design would enable people (EIDD, 2004). One aspect of enabling people has to do with their accessibility to transport. A number of key approaches speak directly to the need for unfettered accessibility, or, at the very least, design should offer a modicum of support to disabled people to allow them access to an independent lifestyle.

1.3 Design for accessibility: A review of key approaches

Accessible Design attempts to make the interactive environment (products, places and spaces) "more usable by people with disabilities" (Vanderheiden, 2001:65). According to Wijk (2001), by using the term *accessibility* one implies an interim, transitional or stop-gap measure. Thus, the design addresses core challenges in the activities of daily living (ADLs). Steinfeld (2001), however, points out the limitations of accessible design:

> "Accessible Design acknowledges that people with disabilities have a right to access and use of products and [built] environments, but it does not go far enough because it does not express social integration."

Edeholt (2004, cited in Jönsson & Certec, 2006b) suggests that design should be a part of the solution. Wijk (2001), however, criticises the lack of education and training with respect to accessible design to which designers and architects are exposed during their studies. The challenge is that an idealised and unrealistic anthropometric framework was used, thus leading to a "training of the average" approach rather than a more in-depth focus on an anatomical, psychological and anthropological diversity. Barrier-free design found its roots in the effort to address these challenges.

Barrier-free Design (BfD) was born out of a response to discriminatory architectural design, also referred to as 'architecture of apartheid' (Gleeson, 2001:153). This concept formed the framework for designing for the needs of wheelchair users. BfD is closely related to *Universal Access* (UA), and also complements the idea of *reasonable accommodation,* the aim of it being to "reduce the impact of the impairment on the person's capacity to perform the essential functions" required of them (South Africa, 2003b:13). BfD, however, is inherently limiting in that it treats the disabled person as a *special provision* focus rather than a core design focus (Goldsmith, 1997; 2000; 2001).

Design-for-All, as a discipline, has its foundation in Europe in the form of the *European Universal Design Principles* or *European Concept for Accessibility* (Wijk, 2001; European Commission, 2002; EIDD, 2004; Coleman, 2006; EDeAN, 2006; Klironomos, Antona, Basdekis, & Stephanidis, 2006). Currently, Design-for-All (DfA) is similar to *Inclusive Design* and *Universal Design – Inclusive Design* evolving in the UK and USA (Naess, 2003; Design Council, 2006; EDeAN; 2006; Tiresias, 2006). Proponents of UD and DfA concur in their discussions about accessibility and disabled people. DfA is also prioritised in the European Union and on governmental levels in its member countries.

Design for disability can also be described as *Design for Special Needs* and relates to the medical model of disability, the main focus being on aids and adaptations to everyday equipment and buildings (Clarkson, Coleman, Keates & Lebbon, 2003:599). Design was undertaken with the intent of being prosthetic, with its origins in post-trauma rehabilitation of war veterans. This approach has been superseded by the framework and guidelines of *Inclusive Design* in Europe. The various approaches to offering increased access and to support users who may be differently abled heavily influences the field of ergonomics –including a number of professional fields, such as industrial design.

1.4 Ergonomics: A brief introduction

Wilson (1990:3) states that ergonomics is about "designing for people". Ergonomics places emphasis on people as the focus of design, thus conforming to a User-Centred Design approach. It did, however, fail to recognise any *special human needs* until 2001 (Danford & Tauke, 2001). *Ergonomics*, *User-Centred Design* and *Inclusive Design* are all equal concepts (David, 2001). According to Wells et al. (2003:5), there is no argument against "ergonomics as human-centred design". Pheasant (1998:23) explored the principle of the 'limiting user', finding a 65% lean towards 'Extra-Ordinary' individuals, the limiting factor being an exclusive focus on *reach* and *clearance* (in relation to *anthropometric* characteristics).

Anthropometrics, a branch of ergonomics, involves all measurements of the human body, such as size and strength (Pheasant, 1996:7). An attempt at perfecting the *anthropometrics* approach in the form of ergonomic design guidelines for special populations was compiled by Kroemer et al. (2001): *Extra-ordinary Ergonomics,* a work dedicated to the ergonomics of "*Small and Big Persons, the Disabled and Elderly, Expectant Mothers, and Children"* (Kroemer, 2006:1). The emphasis of this work is that "the common user population is a group of individuals with diverse characteristics and varying capabilities". Table 1.1 (Kroemer, 2006:77) summarises the diverse population ergonomic differences found in his research.

TABLE 1.1: EXTRA ORDINARY TRENDS AND CHANGES IN FUNCTIONING

(Kroemer, 2006:77)

	Energetic Capabilities (metabolism, circulation, respiration)	**Biomechani-cal Capabilities (strength, power, mobility, endurance)**	**Sensations, Perception, Decision Making, Controlling Actions**	**Capabilities to Endure and Function in Heat and Cold**	**Stress Tolerance**
PREGNANCY	*reduced, diminishes further with run of pregnancy*	*reduced, diminishes further with run of pregnancy*	*no change except in taste and smell*	*reduced, diminishes further with run of pregnancy*	*reduced, diminishes further with run of pregnancy*
CHILDHOOD	*much smaller but increases*	*much smaller but increases*	*not systematically known*	*much smaller but increases*	*not systematically known*
AGEING	*reduced, diminishes further with ageing*	*reduced, diminishes further with ageing*	*reduced, diminishes further with ageing*	*reduced, diminishes further with ageing*	*depends on individual and circumstances*
WITH PERMANENT DISABILITY	*no general statements possible, depends on the individual*				

"Extra-ordinary" ergonomics focuses on groups that are disadvantaged when data for the 'average' or '50th percentile' individual are used as a reference to represent the user population. These "extra-ordinary" groups "who differ from the average adult model [include]: pregnant women, children, and ageing and old persons, as well as those with disabilities" (Kroemer, 2006:4).

The design disciplines researched have at the core a focus and aim to better the lives of individuals by addressing the design of products and systems that are in daily use. In the South African context, one such system that may benefit from design intervention is that of public transport.

1.5 Problem statement

This thesis deals with the lack of adequate public transport resources combined with the need for independence in disabled drivers increased the use of driving simulator as a means to train and obtain a driver's license. Although these simulators can accommodate disabled drivers, limitations are still found in the type of disability they can accommodate. This project aims to provide an adaptive product that can accommodate as many disabilities as possible.

1.6 Background to the Problem

In a South African context, disabled people struggle with IADL tasks - in particular, with mode of transport challenges, as defined by Lawton and Brody (1996). IADL tasks and the inability to perform these have a direct impact on a person's ability to live independently (Weston, 2009). According to Driving Ambitions, a driving school for disabled drivers founded in 2012, "public transport has not been adequately integrated and updated to accommodate the needs of disabled people. Thus personal transport and the assistive technologies used to adapt these vehicles have to be explored" (Driving Ambitions, 2012). The Integrated Rapid Transit (IRT) system is currently addressing the public transport need of disabled people. The challenge is, however, that the system is still under development in certain areas of Cape Town (City of Cape Town, 2016). The Bus Rapid Transit (BRT), which forms part of the IRT system, has been established in Khayelitsha, Mitchells Plain, the City and Atlantic suburbs, Montague Gardens and Century City, West Coast suburbs and Atlantis area (City of Cape Town, 2016). Although the public transport system in Cape Town has been integrated, it does not yet reach all areas, rural and urban, to accommodate the needs of differently abled people. Thus personal transport and the assistive technologies used to adapt these vehicles have to be explored as one of the main methods of transport for differently abled individuals (Driving Ambitions, 2012).To understand fully the shortcomings of personal transport, an in-depth study of the statistics regarding disability in South Africa could would be of great use.

In 2003, the United Nations estimated a 10%-12% portion of the world population to be disabled. The South African Census statistics for 2001 indicates a much lower 5% for South Africa (Stats SA, 2005a:1). This percentage might not be an accurate representation due to under-reporting as a result of social stigma associated with disability or inadequate data capturing methods (ODP, 1997; Child Health Policy Institute, 2001; WHO, 2002). Compared to Stats SA, the Integrated National Disability Strategy published a more realistic 5%-12% disabled population percentage for South Africa (ODP, 1997).

According to Statistics South Africa's census, the percentile of the population that lives with a disability does so within the range of, but not limited to, cognitive to physical, and mild to severe. Of the documented 5%, the age group 20 years and above forms 3.5%. Most individuals in the group mentioned suffered from either a sight or physical disability

(Lehohla, 2005:13). It is noted that in higher education institutions 3% of individuals have some type of disability (Lehohla, 2005:13-15).

Including over 200 000 people with physical disabilities in a research study could be a daunting task, since each disability has some form of uniqueness. Thus, within the context of this project, a single individual took part in the participatory research activities: Participant X. Participant X has an extensive range of physical disabilities that directly impact her ability to drive. Although participant X acted as the main research collaborator, the focus of the project was on differently abled drivers in general. Participant X has a history of struggling to obtain her driver's licence due to her disability; thus, her background and experiences were of vital importance to the research project.

Participant X was born with PFFD and Phocomelia[1]. Nevertheless, regardless of her disability, she has her own practice as a Clinical Physiologist. Personal transportation plays an important part in her studies and the development of her career; because she has to travel between patients and the hospital (Participant X, 2012). In 2001, she obtained her driver's licence at the traffic department in Stellenbosch. This posed a challenge since participant X had to go through various training schools before she found one that was willing to help her complete a learner's course. No training school could be found that had a simulator or an adapted vehicle which could be used in teaching Participant X to drive. Thus she had to buy a vehicle to learn to drive. Due to the unique combination of disabilities mentioned, participant X can be seen as a 'limiting user'. Pheasant introduces the principle of the 'limiting user'. A 'limiting user' is a member of the user population who, because of his or her physical characteristics, imposes the most severe constraint on the design of a product (Pheasant & Haslegrave, 2006: 27). Chapter 2 discusses the limiting user at greater length.

1.7 Simulators as a means: Developing assistive technologies for differently abled drivers.

The question raised by differently abled drivers regarding driver training in simulators remains: Can simulators be used for driver training? The University of Alabama shed some

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[1] PFFD: A rare, non-hereditary, birth defect that affects the pelvis, particularly the hip bone and the proximal femur. The disorder may affect one side or both, with the hip being deformed and the leg shortened (Nicky's Drive, 2010) Phocomelia: Congenital absence of the proximal portion of a limb or limbs, the distal parts being attached to the trunk by a small, irregularly shaped bone (Farlex, 2012a)

[2] Speed of Processing- time taken to process information.

[3] Consent was given for the use of this name and surname, see appendix A and B.

light on this question, although their testing was done on able-bodied drivers. [2]*Speed of Processing* while driving was evaluated by the University of Alabama at Birmingham. It was found that over a period of 18 months of training in a simulator, using various tasks, there was a substantial increase in driving ability. This training resulted in fewer dangerous manoeuvres while driving. Over the period of 18 months, 456 drivers were tested (Roenker et al., 2003:218).

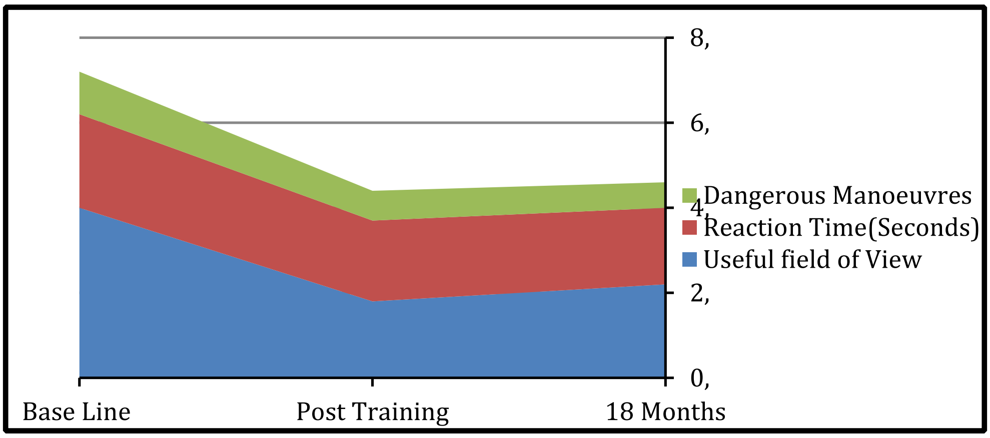

FIGURE 1.1: IMPROVEMENT IN VARIOUS SKILLS REQUIRED WHEN DRIVING

(Designed by author, 2014, based on findings by Roenker et al., 2003:218)

Figure 1.1 illustrates three tests that were carried out. Before training commenced, values were obtained in dangerous manoeuvres during driving, as well as reaction time and useful field of view. It was found that an average of 40% to 50 % improvement was made after simulator training; the improvement was still observed 18 months after training in the simulator (Roenker et al., 2003:218). This finding suggests that simulators can be used in certain driver training environments with relative success. Furthermore, in a vehicle accident the probability of a fatal injury is a reality. In many other industries simulators have been adapted to train, rehabilitate and test certain abilities or skills.

1.8 Objectives

- The study aims to combine Universal Design with a Case study research approach in the context of disabled driver training using a simulator.
- Produce a working prototype and adaptive aid system for simulators.
- To develop and evaluate this system with a limiting user as a participant.

[2] Speed of Processing- time taken to process information.

According to Weir (2010), simulators provide a good platform to evaluate drivers. It is based on Weir's statement that I proposed the following research questions:

Main Question: How do human factors affect the development of simulator controls for differently abled drivers?

Sub-Question 1:
Which product and automotive factors influence the adaptation of assistive controls?

Sub-Question 2:
Which contextual factors influence the adoption of an assistive control system?

Sub-Question 3:
How can a simulator be developed with the focus on UD criteria *and meta-design approaches*?

1.9 Research Design

Thomas (2011) states that a case study is a scientific approach that concentrates on one instance of a phenomenon. Case study research is meant to focus on detail of a study and aim to research the chosen subject study in itself as a whole from many angles. Stake (2005:433) states it as follows: 'Case study is not a methodological choice but a choice of what is to be studied'. The focus of the case study can be a person, group, institution, a country or an event - in theory, any aspect that the researcher wishes to study (Thomas, 2011). Case Study Research comprises two parts (see Figure 2). First, there is a subject and, second, an analytical frame within which the research is carried out (Wieviorka, 1992:159). The case study reported upon in this dissertation revolved around a driver with a unique disability profile in a specific context with a specific vehicle.

FIGURE 1.2: THE TWO PARTS OF A CASE STUDY

(Designed by the author according to findings by Wieviorka, 1992:159)

Case study research consists of three steps: understanding the purpose, choosing an approach and, lastly, the process required for the case study; in essence the what, why and how of the study. These three steps formed the structural framework for this dissertation. Due to the nature of conducting a case study research on one person (a limiting user), the three steps mentioned were carried out in more than one cycle, thus gaining more focus and in-depth understanding during the research process. This case study research approach is further explained in Chapter 3. A visual model was constructed to serve as a map key (see Figure 1.3). Once the research design was understood, priority was given to the research approach.

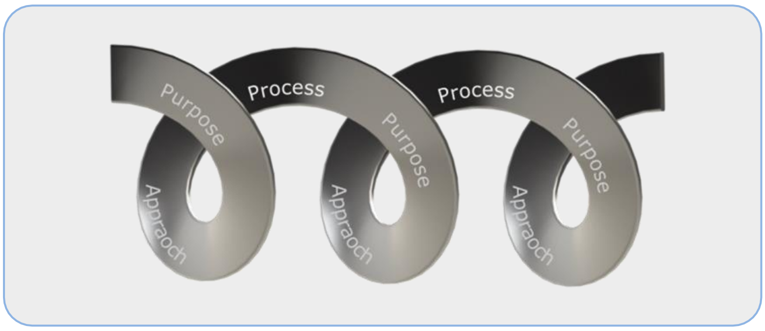

FIGURE 1.3: DESSERTASION MAP KEY

(Designed by the author according to findings by Thomas, 2011)

1.10 Research Approach

When carrying out research with a limiting user as a participant, the right frame of mind is crucial to the success of the research outcome. Meta-design and participatory design formed an important element the research approach. Meta-design keeps in mind that, as professionals in different sectors, we have different abilities and skills, as well as talents (Fischer, 2003:2). For example, a mechanical engineer has skills that can only be obtained in his field of study; the same could be said of megatronics, product designers and IT technicians, amongst others. If a product were to be successful, various professionals would have to combine their areas of expertise and cross-pollinate the participatory design process (Fischer, 2003:2). Participatory design (PD) thinking and approach aims to involve users in the design process, the preferred outcome being to empower users as co-designers (Schuler & Namioka, 1993). PD supports diverse ways of planning, thinking and acting that answer to human needs.

Participatory design, as explained by Fisher, focuses on activities and processes taking place with respect to a product or system at the time of research and design. Thus, little attention was paid to the living entities that partook in the research. This approach put the users in a reactive role (Fischer, 2003:2). On the other hand, Teoh (2013) found that, when conducting interviews with a stakeholder, the user-centred research approach dictated that the stakeholder be comfortable and at ease with the environment as far as possible. The process of gathering information was unobtrusive. The focus was as much on the user's experience as it was on the task of obtaining information. Four basic steps were used in the process.

According to ISO 13407 (Teoh, 2013) these four essential activities are:

- Requirements gathering – understanding the context of use
- Requirements specification - Specifying the user requirements
- Design – Producing designs and prototypes
- Evaluation - User feedback is analysed to improve the design

Participatory design complements case study research in the sense that the user, or limiting user, is involved in the research approach.

1.11 Significance of the Study

The study is the first of its kind in South Africa addressing the need of disabled drivers to train for the driver's license without requiring personal transport. The findings will lead to a simulator prototype that accommodates a wider variety of disabled drivers that wish to obtain their driver's license. The research work will benefit all designers and developers of adaptive aids for disabled drivers. The extent of the project also lends itself to combining UD principals with Case Study Research which is also unique in its approach and application. A team of participants and stakeholders are required thus the exposure to interdisciplinary communication and teamwork will benefit each individual as well as the researcher and academic community.

1.12 Summary

This chapter speculates that simulators could be used as a training platform for drivers. From findings with regard to simulators the research question arises: How do factors affect the development of simulator controls for differently abled drivers? The main research question led to three sub-questions regarding product and automotive factors influencing adaptive steer by wire controls. Contextual factors need consideration, as well as how a simulator can be developed with the focus on a Universal Design criterion. Design challenges were encountered, and a limiting user, representing the disabled community, was chosen as a partner in researching the challenges faced. A case study framework was the foundation to the research design. The research design consisted of three steps that were iterated in more than one cycle with the aim of gaining focus and in-depth understanding of the research question. Meta-design and PD served as design approach. The research process and findings are documented in the following chapters:

- ***Chapter Two: Literature Review***

Chapter two aims to discuss the literature findings pertaining to the purpose and approach of this study. Factors discussed are the understanding of the term 'being a safe driver', followed by research into motor disabilities, their effects on driving, as well as which areas of the body they affect. Topics linked to the research approach are case study, PD and meta-design approaches in other disciplines relating to design.

- ***Chapter Three: Methodology***

Chapter three elaborates on case study research as a methodology with the aim of clarifying the practical approach and process specific to this thesis. PD and meta-design principles complementing the study approach and processes will also be discussed. The methods used in case study research will also be quantified in this chapter.

- ***Chapter Four: Design***

Chapter four will discuss the design challenges, practical approach and process in the field specific to the case study chosen for this dissertation. Design prototypes and interventions will be tested and evaluated along with input from the limiting user.

- ***Chapter Five: Findings***

Chapter five will reflect on the design challenge, approach and process with the aim of stating an argument in favour of the design outcomes of the case study.

- ***Chapter Six: Conclusion and Recommendations.***

Chapter six will discuss the main research question and the simulator designed as an answer to the research question. The adaptive aids designed for the simulator are also reviewed as well as which challenges they address and how each one links with a set of UD criterion. Chapter six ends with limitations of this dissertation and recommendations for further study.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter discusses the findings documented in and which pertain to the purpose and approach of this study. To be able to understand the main problem, key focus areas were researched:

- Understanding personal transport aspects required for independent living.
- An overview of the statistics with regards to differently abled persons in South Africa, and how many people would be affected by this study.
- A discussion of different models of disability.
- How disability is categorised.
- An analysis of the most extreme cases of disability.
- How participatory design enables the designer to design in collaboration with the differently abled user.

Once participatory design is explored, certain design elements, such as ergonomics and understanding the limiting user, play vital role in facilitating such participatory design with the limiting user. Participant X , a differently abled driver, represents the limiting user in this study due to her unique set of disabilities. Her challenges with driving, as well as road safety, lead to the evaluation of what is considered to be a safe driver in different contexts. To understand better safe driving, one has to look at what affects a person who is driving, as well as what affects the limiting user, or differently abled driver, when driving. The available information/research on relevant technologies was employed to address the present challenges experienced by limiting users and how to support them. This chapter ends by formulating the main design challenge in this study.

2.2 Activities of daily living (ADL)

An activity of daily living (ADL) involves caring for or moving one's body. Activities such as walking, bathing, dressing, toileting, brushing teeth and eating all form part of ADL. Instrumental activities of daily living (IADL), on the other hand, are activities that people do once they have taken care of themselves (Weston, 2009). These tasks enable people to live independently. Many people can, however, still experience an independent live while requiring help with one of the following tasks: cooking, driving, using the telephone or computer, shopping, keeping track of finances, and managing medication (Weston 2009). Lawton and Brody classifies the IADL task of driving under mode of transport. Mode of transport involves independent travel on public transport or using personal transport, arranging travel via a taxi, travel on public transport when accompanied by another as well as travel by taxi with the assistance of another (Lawton & Brody 1996).

In a South African context, differently abled people struggle with IADL tasks in particular mode of transport challenges as defined by Lawton and Brody (1996). IADL tasks and the inability to perform these have a direct impact on a person's means to live independently (Weston, 2009). Driving Ambitions, a driving school for differently abled drivers founded in 2012, that "public transport have not been adequately integrated and updated to accommodate the needs of differently abled people thus personal transport and the assistive technologies used to adapt these vehicles have to be explored" (Driving Ambitions 2012).

The Integrated Rapid Transit (IRT) system is currently addressing the public transport need of differently abled people, the challenge however, is that the system is still under development in certain areas of Cape Town (City of Cape Town 2016). The Bus Rapid Transit (BRT) that forms part of the IRT system have been established in Khayelitsha, Mitchells plain, the City and Atlantic suburbs, Montague Gardens and Century City, West Coast Suburbs and Atlantis Area (City of Cape Town 2016). Although the public transport system in Cape Town has been integrated, it does not yet reach all areas rural and urban to accommodate the needs of differently abled people. To fully understand the shortcomings of personal transport a study of the statistics surrounding disability in South Africa could shed some light.

2.3 SA differently abled population – Statistics

As research were conducted on data specific to differently abled driver statistics it was noted that none could be found, the data found was on differently abled people in general, what follows is the census data for South Africa up to 2011.

In 2003, the United Nations estimates a 10-12% of the world population to be differently abled. The South African Censes statistics for 2001 depicts a much lower 5% for South Africa (Stats SA, 2005a:1). This percentage might not be an accurate representation due to under reporting because of social stigma associated with disability or inadequate data capturing methods (ODP, 1997; Child Health Policy Institute, 2001; WHO, 2002). Compared to Stats SA the Integrated National Disability Strategy published a more realistic 5 to 12% differently abled population percentage for South Africa (ODP, 1997).

According to Statistics South Africa census, the percentile of the population that live with a disability does so within the range but not limiting to, cognitive to physical, and mild to severe. Of the documented 5%, the age group 20 years and above form 3.5%. Most of the group mentioned, suffered from either a sight or physical disability (Lehohla, 2005:13). It is noted that in higher education institutions 3% have some type of disability (Lehohla, 2005: 13-15)

The 2011 Census profile of persons with disabilities in South Africa were conducted using 6 functional domains, namely seeing, hearing, communication, remembering, walking and self-care (Lehohla, 2011). Of these six profiles, self-care corresponds with the list of ADL and IADL. The 2011 Census records 7.5 % of the south African population to be differently abled, this percentile amounts to 2, 870 130 Million people. Analysis of the six profiles indicated that 2% of the differently abled community had self-care difficulty, this amounts to 837 363 with mild difficulty and 588 869 with severe difficulty performing activities of daily living. It is also important to note that 2.5% of persons reported having difficulty walking (Lehohla, 2011) this amounts to 1, 426 232 million people, thus public or personal transport need to accommodate the differently abled finding ADL and IADL tasks challenging. The views on disability and how disability is categorised are more clearly defined by the different models of disability.

2.4 Models of Disability

Currently three models of disability exists. These three models of disabilities are compared in Table 2.1 (M'Rithaa, 2010). The medical model of disability lays undue emphasis on the medical or clinical diagnosis of an individual. This leads to a distorted view of the person in a social standing (Anon., 1993).In order to understand better disability as an experience, we need to see past the medical facts of a diagnosis; they are, however, necessary to determine medication. Nevertheless, the challenge is not to use medical facts to determine the lifestyle that the person should lead. We have to start building an image of what it is like for a differently abled person to live in a world designed and created by and for non-disabled people. In treating the experiences and opinions of differently abled people as valid and important, we achieve this goal (Anon., 1993). According to Oliver (1990), the social model for disability differs from that of the medical one in that the differently abled community does not deny the challenges of disability but locates it within society. "It is not individual limitations, of whatever kind, which are the cause of the problem but society's failure to provide appropriate services and adequately ensure the needs of differently abled people are fully taken into account in its social organization" (Oliver, 1990). The bio-social model has a holistic approach which takes into consideration both the individual, as well as the social and environmental factors, in which a differently abled person will function and live (M'Rithaa, 2009).

TABLE 2.1: CONTRASTING THE MEDICAL, SOCIAL AND BIO-SOCIAL MODELS OF DISABILITY

Medical Model	Social Model	Bio-social model
• personal tragedy theory • personal problem • individual treatment medicalisation • professional dominance • expertise • adjustment • individual identity • prejudice • attitudes • care • control • policy • individual adaptation	• social oppression theory • social problem • social action • self-help • individual/collective responsibility • experience • affirmation • collective identity discrimination • behaviour • rights • choice • politics • social • change	• bio-social theory • personal/social problems • individual/social action • medical/self-help • collective responsibilities • expert/lay experiences • individual/collective identities • prejudice/discrimination • care combined with rights • control combined with choice • political and policy change • individual adjustment and social

Understanding the holistic bio-social disability model is important to be able to formulate a research approach. Considering both a differently abled person's medical condition, as well as the lack of provision in society to accommodate the needs of the person, one has to construct a framework within which to address any design challenge. A starting point can be the ergonomics for the differently abled. One of the main reasons for considering a bio-social medical model is that a differently abled person has a right to independent living. According to the USAID, people with disabilities in Europe and Central Asia face restrictions of movement, have fewer opportunities to participate in civic life or to lead a full, independent life (Shehu, 2011).

2.5 Ergonomics for the differently abled (Limiting User)

Kroemer (2006) addresses design for the differently abled in his book '*Extra –Ordinary Ergonomics'.* Kroemer's view point is to address the so-called 'normal adult' view that most designers have when designing products. He points out that the common user population is made up of individuals with various abilities. Because of the uniqueness of the individual, the ideal design approach would be to design for each individual, if cost would allow it (Kroemer, 2006:3).

Pheasant introduces the principle of the limiting user. A limiting user is a member of the user population who, because of his or her physical characteristics, imposes the most severe constraint on the design of a product (Pheasant & Haslegrave, 2006:27).

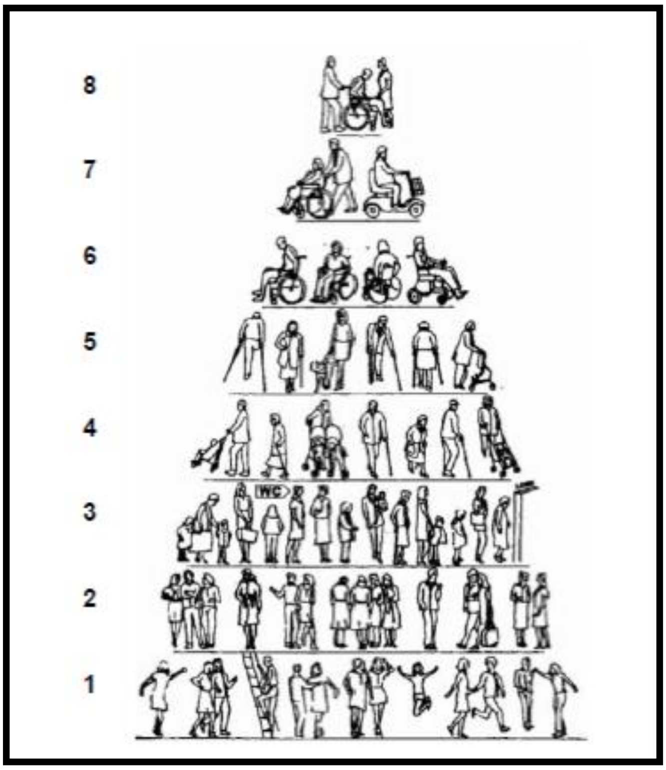

FIGURE 2.1: LIMITING USER PYRAMID

(Preiser & Ostroff, 2001: unknown).

The pyramid (figure 2.1) illustrates that by designing for people with most severe disabilities more people are accommodated in the design (Preiser & Ostroff, 2001: unknown). The above-mentioned pyramid shows a spectrum of users in a bottom-up Universal Design methodology.

- ***Row 1*** represents people who are “fit and agile” and have no trouble running, jumping, leaping and climbing ladders/stairs.
- ***Row 2*** represents users who are regular “able-bodied” people; those who use general facilities and environments without trouble.
- ***Row 3*** introduces the representation of women and children – this is where “architect fails” are noted in the design of user facilities.
- ***Row 4*** introduces the elderly, as well as people with strollers and prams.
- ***Row 5*** represents “ambulant people with disabilities”.
- ***Row 6*** represents independent people with wheelchairs.
- ***Row 7*** represents people who use electric scooters and wheelchairs, as well as people who need an assistant or companion.
- ***Row 8*** indicates those individuals who require two assistants.

2.6 Limiting User Case Study – Participant X

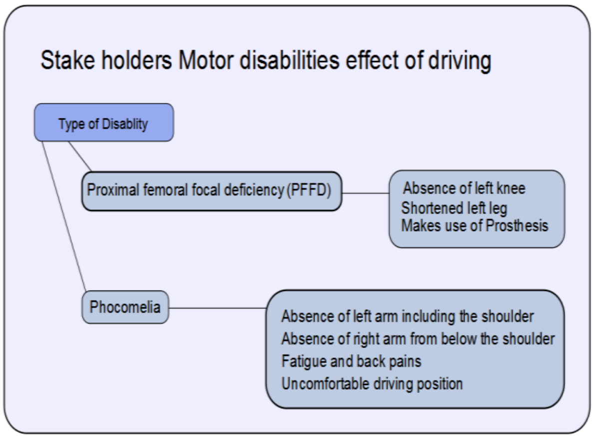

FIGURE 2.2: STAKEHOLDER'S MOTOR DISABILITIES' EFFECT ON DRIVING

(Designed by author, 2014; based on findings by Abdinor, 2012)

In the case of this research study, Participant X [3] falls into the category of the limiting user. Participant X has a unique set of disabilities: she has dwarfism combined with PFFD[4] and Phocomelia. To enable participant X to drive, a list of custom-built adaptive technologies were used in her vehicle. For her to be able to use the brake and accelerator, pedal extensions were added to each. A hydraulic actuator was fitted to her driver-side door so that she could steer with her right shoulder. An infrared beeper button system is activated by participant X prosthesis on her left leg. Participant X uses the toes of her right foot to activate the emergency brake and the automatic gearshift. Figure 2.2 refers to a number of disabilities not mentioned by Ashwin (2004) These had an effect on participant X when she commuted with her Honda Civic (Participant X , 2012). Participant X also shares an overall height with persons diagnosed with dwarfism. Drivers with dwarfism have a challenge reaching the pedals of vehicles.

The challenge participant X faced with regard to transport was that she could not find a driving school that would assist her in obtaining a driver's licence due to the extent of her physical disabilities and challenges with IADL. She is a clinical psychologist and values an

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[3] Consent was given for the use of this name and surname, see appendix A and B.

[4] Proximal femoral focal deficiency (PFFD) absence of the left knee and a shortened leg

Pocomelia is an absence of both arms.

independent lifestyle; thus personal transport was a priority. Due to participant x's career, she had to travel to communities, clinics and hospitals. When a differently abled driver in the UK then donated her an adapted vehicle she could further her career and pursuit of independence. Only when participant X was in possession of the adapted vehicle could she acquire a learner's and driver's licence in South Africa (Participant X , 2012). Nevertheless, participant X still had to conform to the standard rules and regulations of being a safe driver in order to obtain her driver's licence.

2.7 Being a safe driver – Abled and differently abled

Arrive-Alive, a road safety awareness group, considers as an important aspect of being a safe driver being fit to drive the vehicle for which one has obtained a driver's licence. What is understood as 'being fit to drive' is that the person fulfils those conditions that might positively impact the ability to see, think and physically move and act well enough to operate a vehicle safely (Arrive-Alive, 2012). In the case of a differently abled person, the standard interface between the driver and vehicle is not sufficient, but can be adapted to accommodate such an individual. Adapting a vehicle requires one to understand the conditions affecting the driver.

2.8 Conditions affecting limiting user drivers

Upadhyay (2004) researched and stated in his Master's dissertation that certain neuromuscular disabilities are found to be prominent in the driving environment. A large part of Ashwin's list (Ashwin, 2004) of disabilities[5] correlates with the findings of Webaim (2012). Figure 2.3 illustrates three groups of disabilities documented by Webaim and Ashwin. These conditions are diseases or congenital conditions, physical and motor disabilities. Some of the causes of physical disabilities are traumatic injuries, spinal cord injuries and the damage or loss of a limb (Ashwin, 2004; Webaim, 2012).

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[5] These disabilities do not necessarily impact the cognitive abilities of the person. Furthermore, these disabilities could be either acquired or inherited.

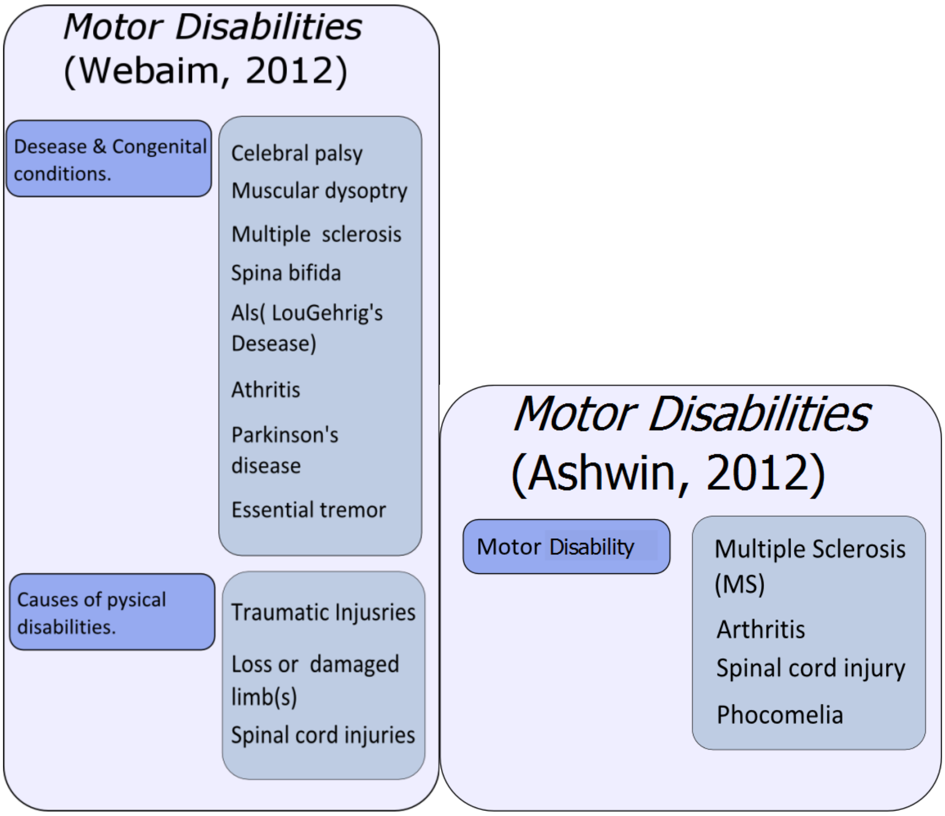


FIGURE 2.3: MOTOR DISABILITIES

(Designed by author, 2014; based on findings by Webaim, 2012; Ashwin, 2004)

Diseases and congenital conditions noted by Webaim (2012) were Cerebral palsy - Muscular dystrophy - Multiple sclerosis - Spina bifida - ALS (Lou Gerig's disease - Arthritis - Parkinson's disease and essential tremors. The motor disabilities recorded by Ahswin (2004) were Multiple sclerosis – Arthritis - Spinal cord injury and Phocomelia. Webaim also noted traumatic injuries, loss of or damage of a limb or limbs, as well as spinal cord injury, to be the cause of physical disabilities.

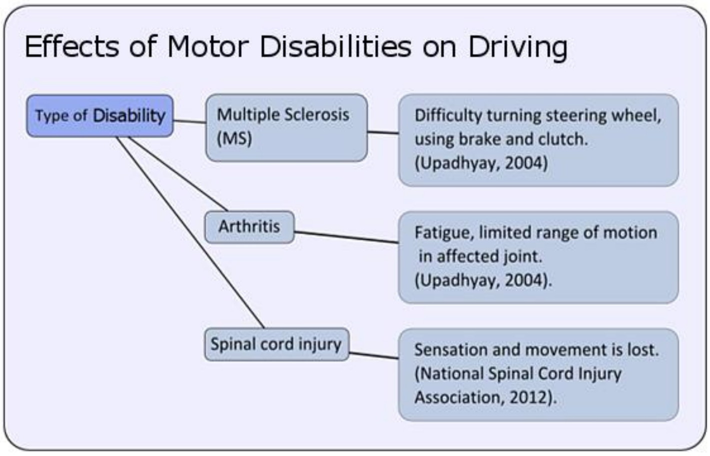


FIGURE 2.4: EFFECTS OF MOTOR DISABILITIES ON DRIVING

(Designed by author, 2014; based on findings by Upadhyay, 2004; National Spinal Cord Association, 2012).

Figure 2.4 illustrates three motor disabilities that affect driving. The first, multiple sclerosis (MS), makes it difficult for the driver to use vehicle-driving controls, since the disease attacks the central nervous system. In general, people with MS may experience partial or complete loss of functions for which the messages are passed through the spinal cord or brain (Upadhyay, 2004).

Arthritis is a disease that comes about with age. Most people over the age of 50 starts to show some signs of arthritis (Upadhyay, 2004). The most common symptoms are pain and swelling of smaller joints in the body, aching and stiffness of joints and muscles, as well as fatigue and reduced range of motion in the affected joints. The effect on driving can be a limited ability to turn the steering wheel of the vehicle, as well as finding it difficult to operate dash controls, turn signal, shift lever and the parking brake (Upadhyay, 2004).

Spinal cord injury can be a fatal condition if not managed properly. Out of 126 patients with Spinal cord injuries admitted to the Duke of Cornwall Spinal Treatment Centre, UK, in 1999, 45% of the injuries were caused by road traffic accidents (Grundy & Swain, 2002). A spinal cord injury affects the part of the body from and below the vertebra that was damaged. Thus, if a person has a spinal cord injury at his or her lower back, the legs would no longer function (Grundy & Swain, 2002). (For a full spinal cord classification, table and assessment on spinal cord injuries please refer to Appendix D.)

To have an indication of different levels of motor disabilities mentioned and which limb or part of the body they affect when driving, please see Figure 2.5.

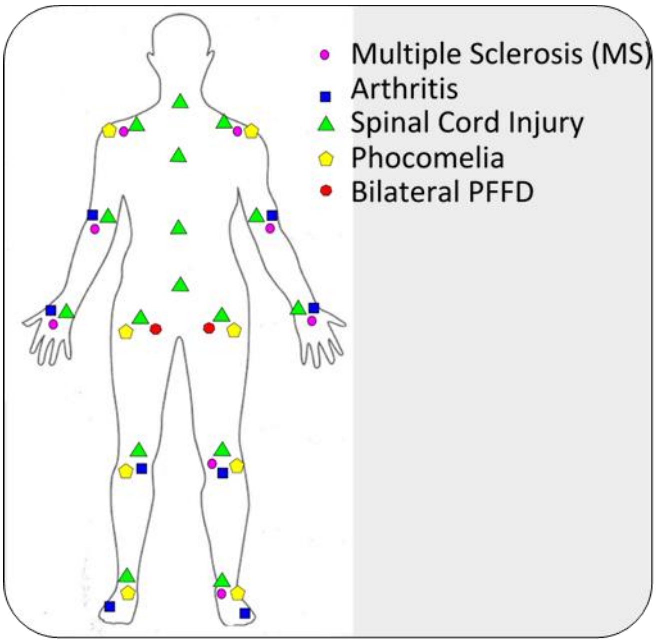


FIGURE 2.5: AREAS OF THE BODY AFFECTED BY MS, ARTHRITIS, SPINAL CORD INJURY, PHOCOMELIA, BILATERAL PFFD

(Designed by author, 2014; based on findings by Ashwin, 2004; Upadhyay, 2004; National Spinal Cord Association, 2012; Webaim, 2012;)

2.9 Achondroplasia type dwarfism

Research done on anthropometric data for people with dwarfism in South Africa is limited. Some of the data found are from a scientific paper addressing orthodontic management in South Africa regarding people with Achondroplasia. General observations state that between 500 and 1000 children with Achondroplasia type dwarfism were seen by dentists. Of the children seen all had normal intelligence and health; some had mal-alignment of their legs (Stephen et al., 2005).

In December 2007, Ferguson completed his Master's dissertation in Industrial Engineering. The title of the dissertation is: *Development of a system for collecting and maintaining Anthropometric measurements for persons with Dwarfism.* It is clear from his research and measurements taken that various differences exist between the anthropometric data collected by Cuffaro in his book *Process, Materials, Measurements* and the data pertaining to persons with Achondroplasia type dwarfism (Ferguson. 2007).

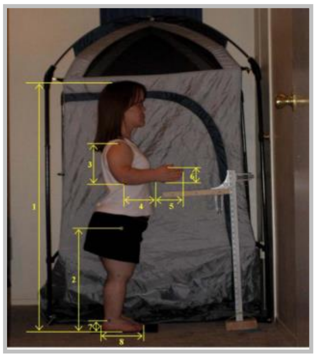


FIGURE 2.6: SIDE VIEW STANDING

(Ferguson. 2007: 22)

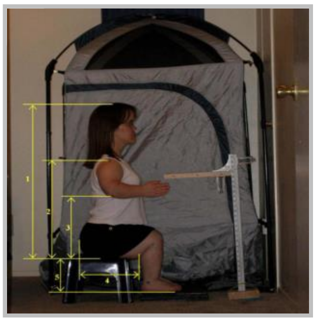


FIGURE 2.7: SIDE VIEW SITTING

(Ferguson. 2007: 25)

FIGURE 2.8: FRONT VIEW STANDING

(Ferguson. 2007: 24)

Figure 2.6 illustrates basic static measurements taken in a trail of a person with Achondroplasia type dwarfism. Figures 2.6 and 2.8 illustrate measurements taken while the person is standing. Measurements taken are stature height, shoulder height, trochanteric height, knee height, ankle height, foot length, upper arm length, forearm length, as well as hand length and hand breadth. Similar measurements are taken with the person in a sitting position, illustrated in Figure 2.7. The measurements taken are: elbow height, knee height, biocromial breadth, hip breadth, foot breadth, sitting height, sitting shoulder height, elbow rest height, buttock to popliteal length, popliteal height and buttock breadth while sitting (Ferguson. 2007).

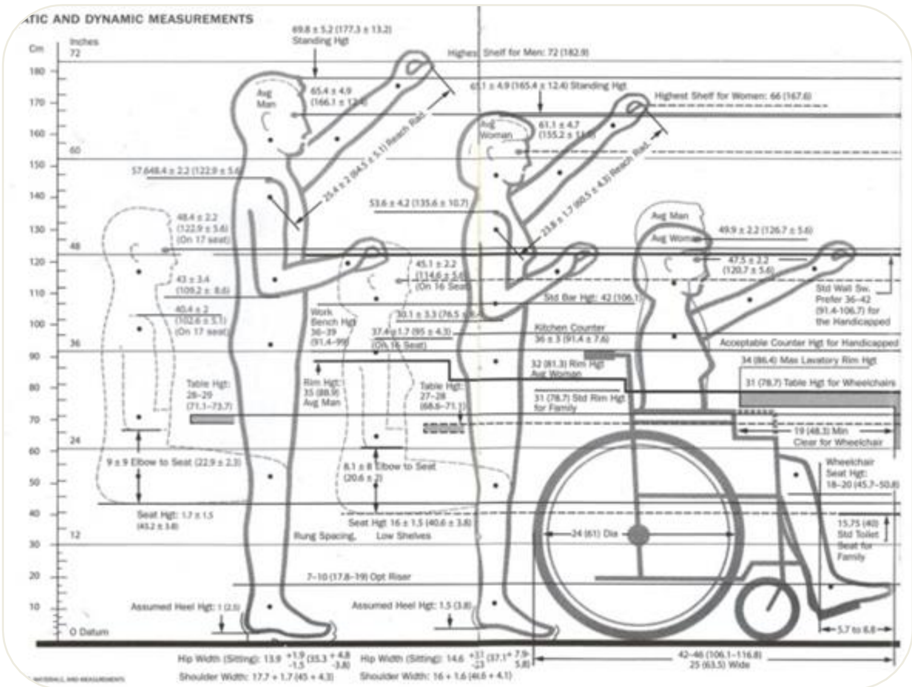


FIGURE 2.9: STATIC AND DYNAMIC MEASUREMENTS OF THE AVERAGE PERSON

(Cuffaro. 2006:124)

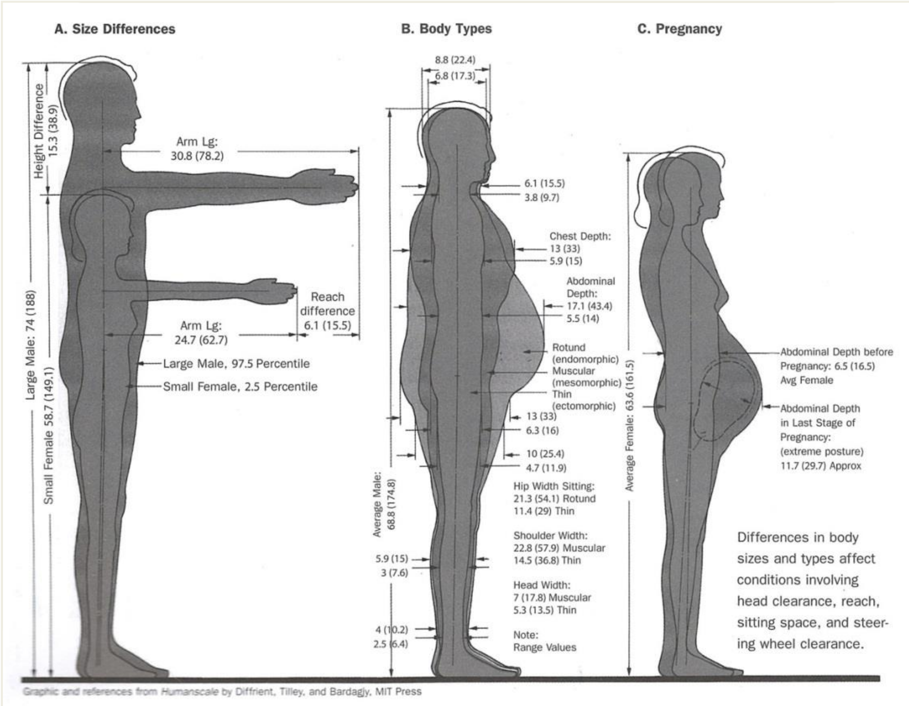


FIGURE 2.10: STATIC AND DYNAMIC MEASUREMENTS OF THE AVERAGE PERSON WITH BODY CHANGE.

(Cuffaro. 2006:127)

Figures 2.9 and 2.10 illustrate the standard static and dynamic measurements of the average person when standing, seated and with body change. The comparison of an average person and a person with Achondroplasia type dwarfism exhibits the different body proportions. Since anthropometric proportions are of vital importance when designing a product, products designed for the physically differently abled will differ from products designed for the average person. Within the framework of adaptive driving controls, different technologies are available to accommodate different challenges faced when driving a vehicle designed for a different set of anthropometric proportions.

2.10 Existing Technologies, Driving Aids

The available technology in a vehicle dictates what adaptive devices can be used. Research on the availability of assistive steering devices shows that many adaptive technologies exist internationally. Companies, such as Howell Ventures, Mobility Product Design (MPD), Independent Living Aids and Fadiel Controls, all provide some kind of adaptive steering control, enabling a differently abled driver to drive an adapted vehicle (Electronic Mobility Controls, 2012; Access Options, 2014). Electronic Mobility Controls

(EMC) sells and installs the AEVIT System, enabling drivers to control their vehicle using drive-by-wire technology.

As individually differently abled drivers have unique requirements, various different products may be used in a system to create an interface between the potential driver and the vehicle simulator that would mimic the normal interface between drivers and their vehicles. These adaptive systems can be divided into two groups; namely, mechanical and electronic controls (Differently Abled World, 2014). (See Figure 2.11, page 37). The environment in which a differently abled driver functions consists of primary and secondary tasks. The primary task is the act of driving. The secondary tasks are those of processing information; for example, getting information either through auditory or visual input while driving (Wickens & Seppelt, 2002).

Drive Master (Figure 2.11) is a mechanical product used to customise various vehicles according to the mobility needs of the driver. Drive Master works on the principle that a hand control is fitted to the steering column of the vehicle. Fitted to the hand control are two adjustable levers. One controls the braking of the car and is directly linked through a mechanical link to the brake pedal. A second link is connected to the accelerator that is activated by forcing the hand control in an anti-clockwise circular direction. Paraplegic drivers can use this type of control (Mobility Works, 2012). The various customisations that can be done are as follows:

- Low effort steering and breaking
- Foot pedal extensions
- Steering knobs or cuffs (Mobility Works, 2012).

AEVIT is a drive-by-wire system or product that consists of primary and secondary driving controls. The AEVIT 2.0 system is made up of various parts in a modular system to achieve its goal as an adaptive aid (Mobility Works, 2012). Although the research focus of the present project is steering controls, it is vital to understand the full product.

Scott driving systems function in a similar way to the AEVIT 2.0 product. The engine and driving controls are connected to a control box from where the driver can control all the electrical circuits of the vehicle, as well as the actuators for the gear shift. All the electrical systems and components are modular, thus making field service easier (Driving Systems Incorporated, 2008). Due to the hydraulic power assisted steering, the steering controls are manipulated by means of a hydraulic actuator. Participant X's 1995 Honda is a good example of such a device (Figure 2.11). The controls used to drive Participant X's car are a hydraulic steering joystick combined with mechanical foot pedal extensions. An infra-red button is used to choose left or right signalling and a linear actuator system is used as a selector for the automatic transmission and emergency brake (Participant X , 2012).

FIGURE 2.11: SALIENT FEATURES OF DIFFERENT DRIVING AIDS

(Designed by author, 2014; based on findings by Mobility Works, 2012; Driving Systems Incorporated, 2008; Participant X , 2012)

Figure 2.11 illustrates the extent and complexity of adaptive driving systems required by various individuals. The complexity of the system is linked to the user’s level of disability.

Drive Master manufactures and installs an adaptive control that transfers the functionality of the foot pedals of a vehicle to hand controls mounted to the steering column of a vehicle. The hand controls are fitted with two adjustable levers. One lever controls the brake function and is directly linked through a mechanical link to the brake pedal. A second link is connected to the accelerator which is activated by applying pressure on the handle in an anti-clock direction. This type of control is aimed at paraplegic drivers (Drive Master, 2013).

Compared to the strictly mechanical system, a drive-by-wire system (AEVIT) allows for improved functionality and customised control of the primary, as well as secondary, functionality. The AEVIT system is a modular system that can be basic in that it is used to control only one function, such as acceleration, or more complex in that it can be used to control various functions, such as steering, braking and acceleration. The system also allows user feedback in the form of a led monitor (EMC, 2013).

Scott driving systems is similar to AEVIT in the sense that it is modular. It is, however, more advanced on the level of integration with the vehicle's own system, and thus has more functionality. Due to the type of design, each function required is linked to a control board. This design is limited due to its space requirement and complexity (DSI, 2008).

In comparison to the above-mentioned systems, differently abled drivers also make use of custom-built systems that suit their particular needs. Participant X makes use of a system in which a hydraulic actuator is used to steer her vehicle. She has mechanical links with a custom pedal system similar to a Drive Master system. An infrared button system is used for secondary functions, such as indicating, as well as a control panel for electric windows and lights. The limitation of such a system is that various suppliers need to be approached for the system components, and, consequently, special expertise is required to maintain the system.

All the above-mentioned systems are available internationally, therefore, limiting support in South Africa (Participant X , 2012). Furthermore, specialist ergonomics considerations are required when fitting any of these adaptive driving aids.

2.11 Main design challenge

The main design challenge formulated due to the above literature findings leads to the question: Can a simulator be developed for differently abled drivers to assist in driver training in South Africa? When designing a simulator for the differently abled, which product and automotive factors influence the adaptation of assistive controls? When considering the adaptive control system, which contextual factors influence the use of such a system? How can the simulator be developed, applying Universal Design criteria?

2.12 Summary

ADLs, and in particular IADLs, make an impact on a differently abled individual's independence. Amongst the differently abled population in South Africa, data for drivers were difficult to find. Thus, an investigation into the general differently abled population struggling with an IADL task was conducted. The bio-social model for disabilities assisted in considering both the person's condition, as well as the environment s/he lives in. To be able to design for the differently abled, the designer needs to understand the differently abled participant. Participatory design is the ideal option as it includes the participant in the design process. Informal interviews and participant observation formed part of the activities of the participatory design process. The ergonomics for the differently abled user led to an understanding of the limiting user who, in this study, was participant X. Understanding participant X unique set of physical challenges led to evaluating what makes a driver a safe driver, the conditions affecting a limiting user when driving, as well as the technologies available to adapt a vehicle in South Africa. This chapter ends with the main design challenge: Design a driving simulator for the differently abled person, applying a Universal Design criterion. Chapter 3 will address the approach and processes of the design challenges specific to this dissertation.

3 CHAPTER THREE: METHODOLOGY

3.1 Introduction

As discussed in Chapter 2, the purpose of this dissertation is to design a driving simulator for a differently abled[6] limiting user. This chapter will elaborate on a Universal Design case study as a research approach specific to this dissertation, aiming to clarify the practical approach and processes used. PD, with a meta-design mind-set, formed part of the design process. The map key below illustrates the approach and process stages discussed in this chapter.

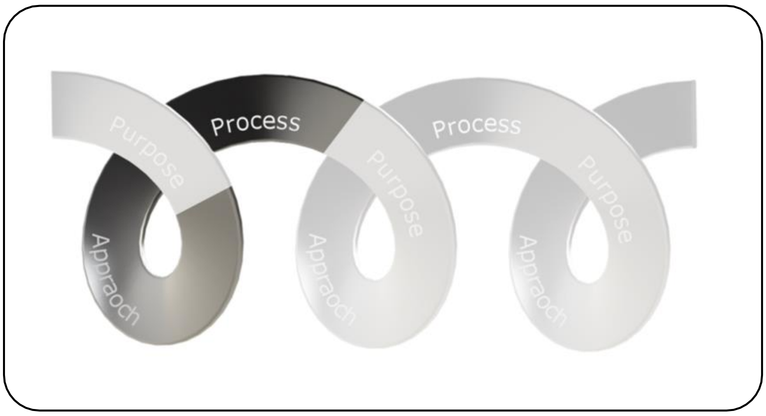


FIGURE 3.1: DISSERTATION MAP

(Designed by the author according to findings by Thomas, 2011)

The dissertation map illustrates the approach and process phases carried out in this chapter.

3.2 Research Design Approach

3.2.1 Universal Design Case Study

By definition Universal Design means that all elements and spaces be accessible to and usable by all people to the greatest extent possible (Dalcher, 2006). This is carried out in all aspects of design through thoughtful planning with the focus on accessibility (Design, 1998:3). The Centre for Universal Design, North Carolina State University assisted in the

[6] Differently abled is used rather than disabled since I believe the first to be a more suitable term used to describe the disabled.

practical application of Universal Design by composing seven principles of Universal Design (Aslaksen et al.,1997):

- Equitable use
- Flexibility in use
- Simple and institutive use
- Perceptive information
- Tolerance for error
- Low physical effort
- Size and space for approach in use

(See Appendix E for a full description of the principles and guidelines.)

For this dissertation, the seven principles of Universal Design were combined with case study research with the aim of designing a product that could be used by as many persons as possible within the limiting user framework.

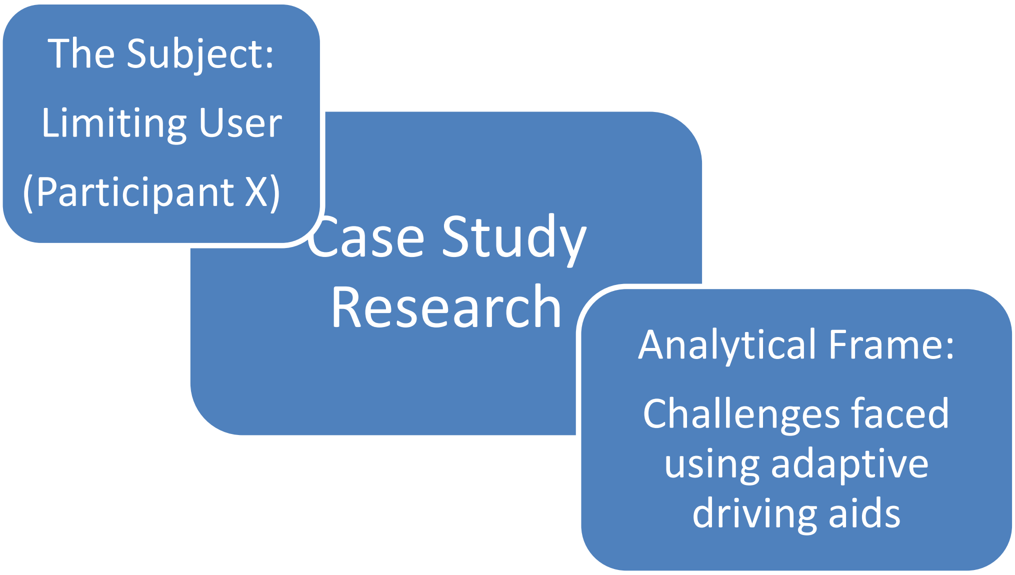


FIGURE 3.2: THE TWO PARTS OF A CASE STUDY

(Designed by the author according to findings by Wieviorka, 1992)

A case study is a scientific approach that concentrates on one chosen subject only. It is meant to focus on the detail of the subject and aims to research it as a whole from many angles. Stake (2005:433) states it as follows: 'Case study is not a methodological choice but a choice of what is to be studied.'

The focus of the case study can be a person, group, institution, a country, an event or any other phenomenon that the researcher wishes to study (Thomas, 2011). Case Study

Research comprises two parts (see Figure 3.3). Firstly, there is the subject, and, secondly, an analytical frame within which the research is carried out (Wieviorka, 1992:159). The case study carried out in this dissertation revolves around a driver within a specific context, with a specific vehicle, having a unique disability profile.

When the decision needed to be taken regarding the research consideration was given to the purpose, approach and the process of the case study. In this thesis, the purpose of the case study was to investigate the challenges of differently abled drivers in South Africa.

The framework of evaluation consisted, firstly, of understanding challenges that the limiting user faced when driving an adapted vehicle; secondly, reflecting on the challenges which the user faced initially and thirdly introducing an invention.

The approach to the case study was to build a prototype that would aim to address the challenges faced by a specific limiting user (Participant X) when driving, the boundary of the process being a snapshot while the user is driving (Thomas, 2011). The analytical frame is the challenges faced by Participant X when using adaptive driving aids in a 1996 Honda Civic.

A concern with regard to the reliability and validity of a case study approach focusing on a single user could be raised (Thomas, 2011). A field interview with a person might produce conflicting results when compared to information from an earlier interview (Yin et al., 2006). To overcome this challenge the interviewer could do data analysis on site: when noticing the conflict in data collected, the interviewer could then alter his or her form of data collection by interviewing a third party or re-interviewing the first participant (Yin et al., 2006).

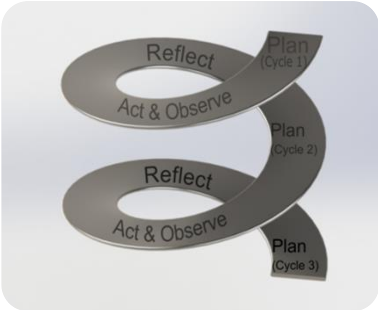
Moreover, Thomas (2009:35) states that 'validity is about the extent to which a piece of research is finding out what the researcher intends it to find out. Consequently, if the data collected from this particular case study answer the questions posed at the beginning of the study, then one should accept the information gathered as valid.

Furthermore, to ensure the quality of the study it was important to make use of triangulation. An example of good triangulation in a case study would be choosing different research methods in different parts of the study with the purpose of "thinking small yet drilling deeper" (Thomas, 2011). Foucault takes a similar approach, we can only really understand something once we have looked at the case from different angles, using different methods (Foucault, 1981). This allowed for a PD design approach in which the chosen limiting user uses a prototype, the designer observes and analyse the findings, applies iterations to a second prototype, and the process repeats itself. This process is further explained in the PD section of this chapter. When the user is involved by means of PD, one has to consider ethics and consent.

3.2.2 Meta-Design

Meta-design keeps in mind that, as professionals in different sectors, we have different abilities and skills, as well as talents. For example, a mechanical engineer has certain skills that can only be obtained in his field of study; the same could be said of mechatronics, product design, IT technicians, amongst others. If a product were to be successful, various professionals would have to combine their areas of expertise and cross-pollinate the PD process (Fischer, 2003:2). Due to this understanding of meta-design, it was imperative to include various skilled professionals in the design process. As the PD process evolved with each cycle, the design brief underwent iterations. According to the design brief, the requirements for a team of skilled professionals needed to assist in the design process could be defined.

3.2.3 Participatory Design



Step 1: Planning/Improving

Step 2: Act/Observe

Step 3: Analyse data, identify design challenges

Step 1 (repeat): Plan design accordingly.

FIGURE 3.3: PD PROCESS

(Designed by author, 2014; based on findings by Kemmis & Mctaggart, 2007: 277)

Part of designing for disability involves understanding the differently abled user. Participatory Design is pivotal to this process. Demirbileka and Demirkan (2004) used a participatory design model in a universal design product_study involving elderly users. Participatory Design sessions were set up using brainstorming, scenario building, unstructured interviews, sketching and video recording. The foundation for the PD approach in their study was that literature showed that: 'a house that is inadequate for the needs of the people living in it, never becomes a home' (Demirbilek & Demirkan, 2004:361). Designs considering data collected from both the psycho-social and physical characteristics of people have a positive effect on the quality of life and promote independence as well as usability (Demirbilek & Demirkan, 1998). This view associates with the bio-social medical model mentioned earlier by M'Rithaa (2009). During the first PD session facilitated by Demirbilek and Demirkan (2004) the participants were seated around a table on which lay a blank sheet of paper for each person. The participants were to sketch their idea of a perfect door handle. The reasoning was that the participants needed to consider themselves as equal partners in the design process. Because of this approach, no perfect drawings were expected, but rather an indication of whether the participants could communicate or express their ideas. As this was an exercise with elderly people using the same approach with disabled people could be beneficial but slightly different in that designing for the differently abled is different from an ergonomics point of view.

According to Kroemer (2006), ergonomics for the differently abled are vastly different due to the unique set of challenges, each individual might face. If a designer wish to design a UD based product for the disabled community the designer are forced to consider a *Limiting User*[7] approach, as noted by Preiser and Ostroff (2001). Case study research was used in other areas of study, such as clinical trials although some concerns were raised. Yin (2012) states that a case study can be used to gain in-depth understanding of a single or small case set in a real-world context. Shehu (2011) carried out various case studies in her research on Universal Design strategies in developing countries. Two case studies were carried out at two different locations. The purpose of these studies was to discuss how two differently built spaces should be improved to adhere to Universal Design standards for differently abled people (Shehu, 2011).

Yin (2011) lists a variety of sources or approaches to obtain evidence or data in a case study. These are:

- direct observations; for example, observing human actions or physical movements,
- interviews which could be open-ended conversations with key participants,
- archival records,
- documents in the form of newspaper articles, letters and emails,
- Participant Observation (PO) in which one is identified as a researcher but also ful- fills a real life role in a real life context. This approach feeds well into PD in that the researcher or designer creates an safe environment in which the limiting user can be part of the design process by using a product while being observed (Fischer, 2003).
- Physical artefacts in the form of employee's work (Yin, 2011).

According to Yin (1993), making direct observations in a field setting involves human action, real-world events and physical environments. Direct observations are one of the most distinctive features of doing a case study. Myerson followed a similar approach in her case study on embedding inclusive design in the design process. Three data collection methods were used in a joint collaboration between the Faculty of Design at Kyushu University and the Helen Hamlyn Research Centre; namely, interviews, observations and workshops (Helen Hamlyn Research Centre, 2005). Rosen-Shoham and Lifshitz (2005) at the Research Centre for Work Safety, Engineering and Industrial Design found that working with hand tools greatly increases a user's risk of developing cumulative musculo-skeletal disorders. When designing a hand tool, it was crucial to incorporate ergonomic

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[7] See *Ergonomics for the differently abled*, p. 6.

principles in the design process. Part of the design process involved ergonomic risk assessment which was achieved by observation and analysis (Helen Hamlyn Research Centre, 2005). Feedback from lead users with the purpose of creating prototypes formed the basis for evaluating and retesting prototypes (Helen Hamlyn Research Centre, 2005). Myerson used a multi-disciplinary approach that resembles Fisher's (2003) meta-design approach.

A second method for acquiring evidence in a case study is open-ended interviews (Yin, 2011). Yin does, however, state that with case study research the researcher may have to do data collection and data analysis simultaneously. The reason is that a field interview with a person might produce conflicting results when compared with the data collected from an earlier interview (Yin et al., 2006). To overcome this challenge the interviewer can do data analysis on site. When noticing a conflict in the data collected, the interviewer can alter his or her plans of data collection by interviewing a third party or re-interviewing the first participant (Yin et al., 2006).

The fifth method mentioned by Yin (2011), participant observation, allows the researcher to illuminate a particular event, to gain in-depth or first-hand understanding of it. The case study research method allows one to make direct observations and collect data in a natural setting, compared to relying on derived data (Bromley, 1986). Participant observation (PO) complements data collection gained by means of interviews, due to the understanding that people's behaviour often contradict their own beliefs and statements (Mack et al., 2005). A disadvantage of PO, as noted by Mack et al., is that it is time-consuming. In traditional ethnographic research, researches spend at least a year in the field, collecting data by means of PO. It is also difficult to document data while practising the act of observing. A third disadvantage of PO is that it is inherently subjective. It is, therefore, important to keep in mind that one has to report or describe what was observed rather than interpret an observation (Mack et al., 2005). Mack et al. provide 11 steps to assist when doing PO. The steps are as follows:

- ***Participant Observation Steps***
  - Preparing for Participant Observation
    - Determine the purpose of the participant observation activity as related to the overall research objectives. Determine the population(s) to be observed.
    - Consider the accessibility of the population(s) and the venues in which you would like to observe them.
    - Investigate possible sites for participant observation.
    - Select the site(s), time(s) of day, and date(s), and anticipate how long you will collect participant observation data on each occasion.
    - Decide how field staff will divide or pair off to cover all sites most effectively.
    - Consider how you will present yourself, both in terms of appearance and how you will explain your purpose to others, if necessary.
    - Plan how and whether you will take notes during the participant observation activity. Remember to take your field notebook and a pen.
  - After Participant Observation
    - Schedule time soon after participant observation to expand your notes.
    - Type your notes into computer files, using the standard format set for the study.

Plattner (2013) states in his field guide that the researcher should do observation in a relevant context in addition to interviews. Plattner observes that some of the most powerful realisations came from when there was a disconnect between what a user said versus what he or she did in a particular situation. Another point to note is that someone might create a work-around for a challenge he or she faced, and failed to mention it. In this case observation can highlight the work-around (Plattner, 2013). Once a design approach has been chosen, ergonomics of the differently abled person and the equipment s/he uses are investigated.

3.2.4 PD as part of this case study

PD within a case study research approach complements case study research in the sense that the user or limiting user was involved in the research approach. To ensure the quality of the study it was important to make use of triangulation. An example of good triangulation in a case study would be choosing different research methods in different parts of the study with the purpose of thinking small yet drilling deeper (Thomas, 2011). Foucault had a similar approach stating that we can only really understand something once we have looked at the case from different angles using different methods (Foucault, 1981). This would allowed for a PD design approach where the limiting user uses a prototype, the designer observes and analyse the findings, apply iterations allow the user to test the product review the findings, reflect and plan for the next PD cycle. Figure 3.1 illustrates the repetitive cycles carried out in participatory design. What follows is a description of each cycle and the steps within each cycle in the PD process.

- ***Cycle 1 - Planning:***

This phase of the design process consisted of an informal interview at the user's workplace, the purpose of which was to understand the challenges that the user faced while driving. After the interview, a design brief was formulated. This design brief influenced the selection of various stakeholders and research collaborators according to the meta-design theory. The design brief also assisted in choosing the way forward.

- ***Cycle 1 - Act/ Observe:***

The observation phase of the first cycle was carried out in the form of an interactive workshop. The limiting user was invited to the Cape Peninsula University of Technology's sports department with the purpose of gaining anthropometric data. As part of the interactive workshop, the limiting user was also observed while driving her vehicle fitted with adaptive driving aids.

- ***Cycle 1 - Reflect:***

After the interactive workshop, Step three of the first cycle consisted of an analysis of the combined findings of the first two steps.

- ***Cycle 2 - Planning:***

Analysis of the first PD cycle led to amendments to the design brief, design approach and processes. The stakeholders were approached and a collaborative design effort was planned.

- ***Cycle 2 - Act/Observe:***

Using the adapted brief and design requirements from Cycle one, the design team constructed a basic modular adaptive system. Low-Fi prototypes were manufactured, aiming to familiarise the limiting user with the team and the design process. Prototypes were used to evaluate the interaction of the limiting user with the adaptive driving aids in the simulator. Ergonomic placement of the driving aids was chosen by involving the limiting user in a fitment workshop. As the workshop was carried out, each step was explained to the user to ensure that she was kept involved in the design process as much as possible.

- ***Cycle 2 - Reflect:***

After the fitment workshop, the findings thus far were noted, and recommendations for the last iteration of the design were made.

- ***Cycle 3 - Planning:***

This cycle consisted of planning the last iteration for the simulator design: deciding on the processes to be employed to evaluate the simulator's performance within the Universal Design case study guidelines.

- ***Cycle 3 - Act/Observe:***

For this step the limiting user was observed using the simulator for an extended period of time. The limiting user was asked to comment on the experience of using the simulator.

- ***Cycle 3 - Reflect:***

This step in the PD process consisted of final thoughts on the success of the simulator design. The user's feedback, as well as any thoughts or recommendations listed by the stakeholders were considered and noted.

3.3 Ethics and Consent

Choosing a limiting user approach for the UD case study renders ethics an important part in the research approach. Ethics are the principles of right and wrong conduct while carrying out a study (Thomas, 2011). Thus, the limiting user should be made aware of the following:

- The purpose of the study.
- The conditions of participating and withdrawing from the study. In this case, ~~is~~ participation was voluntary, and withdrawal was optional and without any conditions attached.
- The interviewee could withdraw permission for the data to be used within two weeks of the interview, in which case the material would be deleted.
- Anonymity would be ensured in the write-up of the dissertation by disguising participant identity if requested.
- The study would involve informal, as well as formal interviews, user testing of prototypes, as well as and not limited to ergonomic and anthropometric data capturing of the participant.

When considering the ethics of a case study, an important part of the study is participant consent. The participant needs to be aware of what s/he agrees to when participating in the study (Thomas, 2011). (See Appendix A and B for an ethics and consent form presented to the participant of this study.)

3.3.1 Applied ethics

Working with a limiting user presented unique challenges since the user was involved in various aspects of the design process according to PD principles. On each occasion of conducting an interactive workshop or scheduling an interview, the limiting user was approached and asked whether she would consider participating. If consent was given and the event was carried out, the limiting user was made as comfortable as requested, especially with regard to the duration of the event. No particular design approach was carried out without permission from the limiting user. All the data collected were kept in an external hard drive with the purpose of safe keeping. As the limiting user had a unique set of physical disabilities, a concern was that offence might be given if an unwanted term be used in conversation or if unwanted information be recorded. Each of these concerns was addressed by asking permission and guidance from the limiting user.

3.4 Inductive Data Analysis

The project used an inductive approach to identify key themes and user experiences. These themes and experiences formed the foundation on which the project's qualitative data were grouped and relationships explored. Key considerations included the tone and attitude of the participant, whether her statements referred to personal or group experiences and the content (actual information) shared with the researcher. From the data gathered during the PD cycles, the key themes were identified. The main focus of the research was to engage with and observe the experiences of a differently abled user while driving an innovative design, which would then benefit the larger differently abled community. During the PD process some patterns were noticed. The dynamics of the design team and their approach to the design needed to be clarified. The design team needed constant reminding of the meta-design mind-set.

3.5 Summary

With the methodology of a Universal Design case study a clear understanding was gained with regard to a preferred process and outcome in gathering research data. PD, combined with a meta-design mind-set, complemented the Universal Design case study research methodology in that it allowed the author to design with the limiting user, selecting stakeholders for the design process, as well as laying the foundation for the field research process between the limiting user and design team. The research process was carried out in various cycles, this cycle approach allowing the designer to gain in-depth understanding of the design requirements. With each cycle of the PD process the study approach could be adapted to assist in the design process. Chapter 4 will elaborate on the Design.

4 CHAPTER FOUR: DESIGN

4.1 Introduction

This chapter will focus on the design process used in the field with the end goal being a product. The three steps within the PD process were applied and iterated in the design phase of the research. The first step consisted of understanding the design challenge, identifying stakeholders and research collaborators, and compiling a design brief. Step two started with field research, by means of audio and visual aids, setting up interactive workshops, observing the limiting user and creating a prototype. Step 3 entailed the analysis of data collected, finalising the design interventions and making suggestions for further research for the next cycle. This 3-step cycle was repeated three times with the purpose of improving the outcome of the design intervention. With each cycle the design process and methods used for field research were adapted to best suit the environment.

4.2 Equipment used: Audio and Visual aids

FIGURE 4.1: GALAXY NOTE 2 10 INCH TABLET

(Author, 2012)

The Galaxy Note 2 used for recordings of audio and visual research.

FIGURE 4.2: INTERVIEW WITH PARTICIPANT X

(Author, 2012)

During an interview with Participant X , she related that it had been made clear to her that in order to obtain her driver's licence, she had to purchase a vehicle from the UK, since there was no product available in South Africa that could be used for training purposes (Participant X , 2012).

When participant x was 18 and could apply for her driver's licence she could not find a suitable vehicle that could be used for her driver training. She had to travel to the UK to view a vehicle that had been donated to her. Although she did not have her licence yet in 2002, the vehicle was shipped to South Africa. "During this year my car arrived in South Africa and I obtained my driver's licence" (Participant X , 2012). Participant X thus obtained a vehicle from the UK before she could train as a driver in South Africa.

TABLE 4.1: DESIGN REQUIREMENTS

	Concept Justification
Design a simulator prototype in which a user within the 'limiting user' category can train for his/her driver's licence.	Major requirement by Participant X during interview on 5 November 2012
Functionality of the simulator should be as with a vehicle.	Included in the design of a simulator: required to simulate a real driving experience, in this case the driving experience of Participant X .
This simulator should be designed within UD guidelines to accommodate as many drivers as possible.	Divined by the author as the simulator would be designed for differently abled users who are unique in their requirements (Kroemer, 2006:3).

The simulator should be the product of collaboration between various skilled stake- holders according to the meta-design theoretical views. The skills required were:	Divined by the author according to literature found on the…
o *Driver (Limiting User)*	Limiting user (Pheasant, Haslegrave, 2006)
o *Occupational therapist preferably with experience in simulators*	Extraordinary ergonomics (Kroemer, 2006)
o *Professional with experience in anthropometrics and ergonomics*	Meta Design (Fischer, 2003)

Considering Participant X needs as a differently abled driver (see Table 4.1), it became apparent that there is a need for a product that can enable people with similar disabilities to obtain their driver's licence. This product could be in the form of a simulator, according to researchers at the University of Alabama (Roenker et al., 2003:218). Due to the interview with Participant X and considering literature findings (See Chapter 2) certain design requirements were formulated.

With the design requirements in mind, the design team requirements were formulated according to the meta-design mind-set. When carrying out research with a limiting user as a participant, the right frame of mind is crucial to the success of the research outcome. Meta-design formed an important part of the research approach because it necessitates that, as professionals in different sectors; we have different abilities and skills as well as talents (Fischer, 2003:2). Needless to say, the limiting user was an indispensible member of the design team; a mechanical engineer was required to assist with understanding the mechanics of a vehicle and simulator. An occupation therapist was approached to assist with understanding the physical effects on a user when using a simulator. A stakeholder knowledgeable in ergonomics and anthropometrics was also included in the team. Various skilled artisans were tasked with the manufacturing of the simulator adaptive systems. The author facilitated the design process as team leader. What follows is a short description of the stakeholders and research collaborators in no particular order, according to the meta-design mind-set.

4.3 Choosing stakeholders and research collaborators

- ***Limiting User***

FIGURE 4.3: ABDINOR, N

(Abdinor, 2015)

According to Preiser & Ostroff (2001), a limiting user is required to define the level of adaptive driving aids necessary for the simulator designed for this thesis. Participant X was the person chosen to represent the limiting user.

> "Nicky Participant X has over 10 years of clinical experience in Psychology. I studied at the University of Stellenbosch where I obtained my BA (majoring in Psychology and Social Work), BA Honours (Psychology) cum laude, and, finally, my MA (Clinical Psychology) in 2004. I completed my Psychology Internship through Tygerberg Hospital, followed by my Community Service year at Lentegeur Hospital's Forensic Unit. My interest in the psychological adjustment to disability developed during the time that I worked as a Consultant Clinical Psychologist at the Western Cape Rehabilitation Centre (WCRC). I have completed the Primary and Advanced Practicums in Rational Emotive Behaviour Therapy (REBT) accredited by the Albert Ellis Institute in New York. I have lectured Psychology to undergraduate and postgraduate students at Varsity College in Cape Town for over eight years. I now focuses my time on my therapy practice, professional speaking and non-profit work" (Participant X , 2015:1).

- ***Occupational Therapist***

FIGURE 4.4: SWANEPOEL, L

(Swanepoel. L, 2015)

Swanepoel is an occupational therapist at USeBenza Assessment Centre Stellenbosch University. She is part of the team that uses current available simulator platforms to do driver competency assessments at the research centre.

- ***Anthropometrics and ergonomics specialist***

The Human Performance Laboratory in the sports department at the Cape Peninsula University of Technology (CPUT) in Mowbray was approached to assist with the anthropometric and ergonomic requirements for this study.

4.3.1 Cycle 1 - Act/ Observe:

The ‘observe’ phase of the first cycle was carried out in the form of an interactive workshop. Participant X was invited to the Cape Peninsula University of Technology sports department with the purpose of obtaining anthropometric data. As part of the interactive workshop, she was also observed while driving her vehicle fitted with adaptive driving aids.

FIGURE 4.5: BIODEX 3 SYSTEM

(Proxomed, 2013)

Figure 4.5 is of a Biodex 3 system similar to the one used in an interactive workshop set-up at the Human Performance Laboratory located at the CPUT Mowbray Campus. The Biodex system that was available could accommodate only certain ergonomic testing of Participant X due to her unique range of disabilities. Thus an analysis of her planti/dorsi flexion was carried out; in other words, the movements of her right leg using the hamstring muscle, as well as the quads where the lower leg is moved forwards and backwards. Due to the constraints of the Biodex system with regard to Participant X movement ability, a decision was taken to use the adaptive equipment ergonomics in her vehicle to estimate the perimeters for initial prototyping.

- ***Observing Participant X while driving her vehicle***

  During the observation cycle, inductive data analysis was carried out and noted in a summarised format:

Hydraulic steering actuator

FIGURE 4.6: CUSTOM FITTED ADAPTIVE STEERING
(Author, 2012)

Challenges involved:

When Participant X drives, she uses a hydraulic actuator. The actuator cup into which she places her shoulder consists of a steel part covered with foam. The hydraulic actuator cup has a specified range of movement.

There is no adjustment available for the steering sensitivity. A possible leaking hydraulic feed pipe could cause major safety risks to the driver. There is not back-up steering device, should the Hydraulic actuator fail.

FIGURE 4.8: ADAPTIVE STEERING MOVEMENT RANGE

(Author, 2012)

Due to the nature of the hydraulic system, there are hydraulic tubes present in the driver's immediate environment. The driver would find herself in a dangerous situation if a leak were to develop in the hydraulic supply lines to the joystick.

FIGURE 4.7: ADAPTIVE STEERING HYDRAULIC SUPPLY LINE

(Author, 2012)

Custom-built extended pedals and switch control box

FIGURE 4.9: ADAPTIVE EXTENDED PEDALS

(Author, 2012)

Challenges involved:

Using the pedals of the vehicle involves Participant X right foot due to constraints in the movement range of a prosthetic on her left leg. Participant X thus use the toes of her right foot to activate certain buttons located at the top of the brake pedal. These buttons activate the emergency brake as well as the gear shift position. Part of the challenge is that a different driver cannot drive this vehicle unless the extended pedals and pedal box mounted to the vehicle floor are removed. A challenge with respect to the button function is that the user has to keep the button depressed until a desired position is achieved in either the gear shift position or the emergency brake position.

FIGURE 4.10: SWITCH CONTROL BOX

(Author, 2012)

Challenges involved:

The use of the switch control box is similar to the switches located above the extended brake pedal. Participant X use the toes on her right foot to depress buttons. The challenges with operating the buttons are two-fold. Firstly, a limited number of functions could be incorporated in the switch housing; secondly, the driver has to break eye contact with the road and look down to confirm whether a function is activated. The driver also has no control over the safety of the vehicle since the vehicle can be started by pressing a start button.

FIGURE 4.11: EMERGENCY BRAKE SET-UP

(Author, 2012)

Challenges involved:

As can be seen in the image, the emergency brake is activated by pushing down the left button located on the brake pedal. There is no indication when the brake is in an adequate position apart from visual confirmation. To release the emergency brake, the switch is moved in an upwards direction. Here the same concern applies: there is only a visual confirmation as to the disengaged state of the emergency brake.

Participant X preferred not to use the emergency brake due to the slow speed at which the brake is activated, thus rendering the brake useless in an emergency situation.

FIGURE 4.12: BUTTONS USED TO ACTIVATE EMERGENCY BRAKE

(Author, 2012)

FIGURE 4.13: SELECTING A GEAR SHIFT POSITION

(Author. 2012)

Challenges involved:

Participant X uses the toes of her right foot to pull or push on a switch. By pulling the switch the gear lever moves towards the driver; by pushing on the switch the gear selector moves towards the park position. A concern regarding the use of the gear selector is that the button used has to be active continuously and a position can only be confirmed visually. With a standard automatic gearbox, a user would have a feedback from the gear selector that would clip into place once in position, this allows for a sensory touch feedback along with a visual indication of the position selected. Due to the adaptive system, this sensory touch is not available since the mechanism was removed to accommodate an electric actuator that serves as the user's hands.

FIGURE 4.14: SELECTING A GEAR SHIFT POSITION

(Author. 2012)

FIGURE 4.15: BUTTON USED TO ACTIVATE A SECONDARY FUNCTION

(Author, 2012)

Challenges involved:

The challenges involved with using the beeper system are minimal. One of the frustrations is that, once a turn signal has been selected, it is not deactivated by the turning of the steering wheel or using the joystick adaption, as in a standard vehicle. The driver has to deactivate the turn signal using the beeper button. The method of activating and deactivating is similar for all the functions programmed into the beeper system.

4.3.2 Cycle 1 - Reflect:

After the interactive workshop, Step three of the first cycle consisted of an analysis of the combined findings of the first two steps. As an overview of the challenges of the adaptive system used in Participant X vehicle, the author was concerned that most of the various parts used had no relation to each other. For instance, the adaptive power steering was a system on its own, and the same could be said of the emergency brake and the beeper system. The adaptive steering posed some concerns with regard to sensitivity adjustments for individual driver requirements. Since user strength differs, it is important to address this concern in the design of the simulator. The added switch control cluster is not positioned at a convenient viewing angle and is limited to the amount of functions it can perform. The extended pedals work well, according to Participant X . A concern would be that, should a different driver wish to drive the vehicle without the use of the added pedals, the pedal platform would be in the way. As mentioned earlier, the emergency brake could be applied, but was rendered ineffective in an emergency situation in which a quick reaction was required. Consequently, Participant X did not use the emergency brake. Selecting a gear position is fairly easy, although the only indication of a gear selected is by visual confirmation. There is no mechanical feedback that would indicate a selected position, as in the case of moving a gear selector by hand. The mechanism responsible for this feedback function had been removed to accommodate an electric actuator that performed the gear selection function. The challenge for secondary functions is that it is a stand-alone system, and some functions do not perform as they should in a conventional driving situation. The turn signal, if activated, should turn off once the driver pulls out of a turn; the one in Participant X vehicle does not. Considering all these challenges allowed for a productive planning phase of the second cycle in the PD process.

4.3.3 Available driving simulator

During the reflecting phase of PD Cycle 1, the stakeholders were approached by an occupational therapist at USeBenza Assessment Centre to attend a lecture and launch of a driving simulator. Dr Classen, a professor and director at the School of Occupational Therapy (Western University, Ontario, Canada), gave a lecture on the use of simulators for rehabilitation purposes. During this lecture, Classen pointed out that one of the challenges, when using driving simulators, was that a user could suffer from simulator sickness in the case of extended use (Western University, 2015).

FIGURE 4.16: DR CLASSEN DEMONSTRATING THE I-DES VSIM C200 SP DRIVING SIMULATOR

(Western University, 2015)

After the presentation, Participant X and the author attended a demonstration of the simulator. The author was allowed to operate the simulator and experienced simulator sickness within 5 minutes of using the simulator in a normal driving simulation. Unfortunately, Participant X could not use the simulator due to the absence of appropriate driving aids which she requires. This finding strengthened the conviction that there was a definite need to develop a simulator based on a UD criteria and according to the seven guidelines formulated by the Centre for Universal Design (Aslaksen et al., 1997). The design brief was amended to accommodate the lack of adequate adaptive aids available within the iDes simulator.

4.3.4 Cycle 2 - Planning:

Considering the findings of the first PD cycle, along with the challenges of the iDes simulator as perceived by the author and Participant X , the design requirements were revised.

TABLE 4.2: DESIGN REQUIREMENTS

Design Requirements	Concept Justification
Design a simulator prototype in which a user within the limiting user category can train for their driver's licence.	Major requirement by Participant X during interview on Nov 2013
Functionality of the simulator should be as with a vehicle.	One essential element in the design of such a simulator should be that it simulates a real driving experience, in this case the driving experience of Participant X .
This simulator should be designed within UD guidelines to accommodate as many drivers as possible. *The UD Guide lines are:* *Equitable use* *Flexibility in use* *Simple and institutive use* *Perceptive information* *Tolerance for error* *Low physical effort* *Accessible approach in use*	Divined by the author as the simulator would be designed for differently abled users who are unique in their requirements (Kroemer, 2006:3). The UD guidelines were added after the viewing of the iDes simulator as a more all-encompassing definition of UD was required, seeing that one should be able to accommodate as many users as possible in the iDes simulator.
The simulator should allow the user to complete different levels of driver training.	Added by the author after the iDes simulator demonstration, upon realising that a learner-driver would need an introduction to using the simulator.

The adaptive equipment designed for the simulator should be an improvement on the current adaptive aids used by Participant X .	Added by the author during the reflection phase of PD Cycle 1. During the observation of Participant X while driving her car, it became apparent that some functions seemed difficult, as well as dangerous, to perform. These issues were noted to be used later in the design process of the simulator.
The simulator should be designed in collaboration with various skilled stakeholders, according to the meta-design theoretical views. The skills required were: *Driver (Limiting User)* *Occupational therapist preferably with experience in simulators* *Professional with experience in anthropometrics and ergonomics*	Divined by the author according to literature relevant to… • Limiting users (Pheasant, Haslegrave, 2006) • Extraordinary ergonomics (Kroemer, 2006) • Meta-Design (Fischer, 2003)

4.3.5 Cycle 2 - Act/ Observe

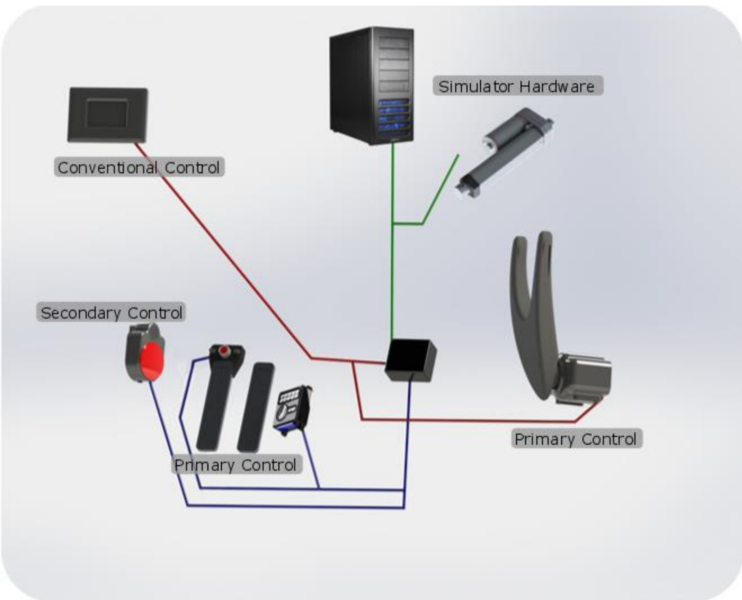

FIGURE 4.17: SIMULATOR ADAPTIVE AIDS SYSTEM MAP

(Author, 2014)

Using the updated requirements, the design team designed a basic modular adaptive system. The system was separated into primary, secondary and conventional vehicle control functions. The primary control functions constituted the minimum functions that allow operation of a vehicle. For this reason they included the adaptations which required a direct user interface. The accelerator and brake pedals fulfilled their usual function, although they had been re-positioned. Steering was done by means of a shoulder-height mounted joystick, and, lastly, since the simulator was an automatic one, the gear shift and parking brake were controlled by means of a button attachment on the brake pedal.
The secondary control adaptations controlled the functions that Participant X could execute while driving, such as the indicators, headlights, and were activated with the aid of a beeper system. The list of functions could be customised for different learner-drivers, but at this stage was programmed according to the functions available to Participant X while driving her car. Once Participant X had driven the simulator for the first time, these functions would be reviewed to accommodate the challenges noted while observing her during the first cycle of the PD process. A list of functions was added to the simulator's main controller adaptive hardware, these were functions that could be performed while a vehicle is stationary, such as the mirror positioning, air conditioning and were controlled by way of the pedal control cluster. Although some of the conventional vehicle control functions were not adjustable in a simulator platform, the realism of the driving experience in the simulator was important; thus these features were added to this simulator design. To understand fully the extent of functionality required from the adaptive aids used by Participant X in the simulator, a more technical understanding of the system was necessary.

4.3.5.1 Adaptations for the simulator

- ***Primary Control Functions***
    - ***Steering***

The steering adaptation took the form of an electrically actuated servo motor that is rigidly connected to the steering column and drives the steering rack input shaft via a reduction gear. The motor, therefore, is expected to perform the same input functions as a human driver using the steering wheel, with the existing power assist electric motor facilitating the task of turning the steering wheel, as well as the wheels, in the simulator. The limiting user actuates this servo motor via a joystick lever mounted either on the door or door column, depending on the simulator vehicle model. This joystick lever takes the form of a U-shaped cup. Participant X would position her shoulder inside the cup and, by moving the lever back and forth, would turn the steering wheel right and left respectively. When the U-shaped cup is released it returns to its neutral position due to a double spring-back return feature.

FIGURE 4.18: ACTUATING THE STEERING WITH THE JOYSTICK

(Author, 2013)

Due to the limited travel that Participant X can execute with her shoulder, the initial idea of matching the joystick lever angular travel with the steering wheel rotation proved to be impractical. This challenge was overcome by dividing the steering into 5 zones, which meant that Participant X needed to move the lever into only five different positions to achieve full steering capability. Figure 4.12 illustrates these five different zones.

FIGURE 4.19: STEERING ZONES AS OBSERVED FROM THE USER'S VIEWPOINT

(Author, 2013)

The figure above illustrates the five different zones; each zone was set up to have a different function. With the joystick lever anywhere inside Zone 1, the steering wheel is in a “straight ahead hold” position; or, upon returning the joystick to anywhere within this zone, the steering wheel would return and “hold straight ahead”. The left and right Zone 2s were set up to be a “cornering hold”, and only come into play when the joystick is returned from Zone 3. As Participant X moved the joystick lever from Zone 1 to Zone 2, the wheels were not moved from “straight ahead”.

Once Participant X pushed the lever into Zone 3, the steering wheel of the simulator started turning, making this the “wheels turn” position. From this it becomes clear that, to achieve constant cornering, Participant X initially needed to push the joystick lever into Zone 3 to achieve the desired turning angle, and then return to Zone 2 and keep the joystick lever steady in order to negotiate steady corners. If a greater turning angle was required, she had to push it a little further into Zone 3 until the required steering angle was achieved, and then return to Zone 2. As an alternative, she could also hold the steering wheels steady in Zone 3. Upon release of the lever, the wheels would return to their “straight ahead” position.

Lastly, to simulate the force feedback that an able-bodied driver experiences through the steering wheel, a torque feedback device was connected to the joystick. This feedback device gave Participant X road surface feedback obtained from the simulator software road conditions. The feedback device increased or decreased the turn resistance of the joystick accordingly. For example, if the steering system “felt” heavier in the simulated environment when turning the wheels on a rough surface versus a smooth surface, the joystick lever would also feel stiffer. This function is not critical to the joystick operation, but rather enables the user to experience a more realistic simulated driving experience. Through unplugging the cable connectors and removing the joystick, the simulator could be restored to its original condition. Once the adaptation main controller is switched off, the power to the servo motor is cut, and it would not affect an able-bodied driver using the simulator. The joystick could also be replaced with a driving aid designed for a different differently abled person’s needs.

- ***Brakes and Acceleration Control***

For this particular adaptation, a pedal box was constructed and mounted to the floor in front of the seat. The pedal box was equipped with a bracket that restricted the seat adjusting lever from being moved, thereby preventing the seat from being adjusted, as well as indicating whether or not the seat was ~~not~~ in its optimal position. The pedal box took the form of a frame with both additional brake and accelerator pedals, securely fitted to provide for their correct operation, and capable of operating through the full range of normal travel. This pedal box elevated both additional pedals to enable Participant X to reach both with her right foot.

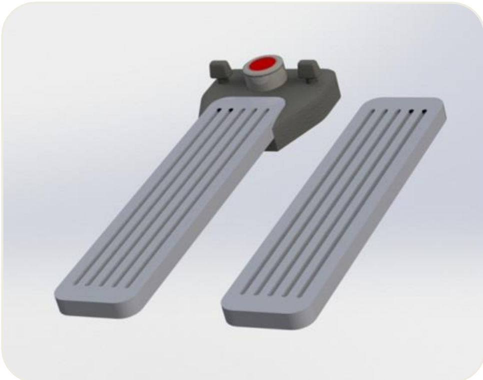

FIGURE 4.20: BRAKES AND ACCELERATION CONTROL

(Author, 2013)

The pedals were connected to the simulator via a wire link. This allows the user or operator to set sensitivity. The pedals function in the same way as conventional pedals in a car would function. The advantage of the wired pedals is that they can be removed, should a different user wish to use the simulator. This feature is in accordance with the UD design approach.

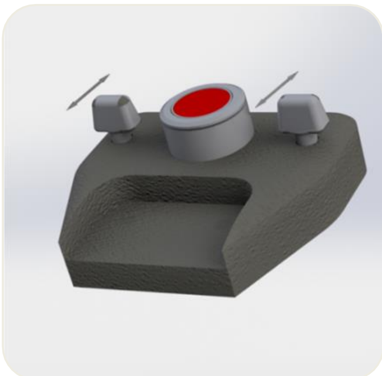

FIGURE 4.21: GEAR SHIFT AND PARKING BRAKE CONTROL FOOT PAD CONTROLLER

(Author, 2013)

Both the gear shifter and parking brake are controlled via an attachment on the brake pedal, housing a set of triple action tip-tronic buttons that allow actuation of the gear shift or emergency brake. For the gear shift, up-or-down button movement means back-and-forth lever movement when selecting the appropriate gear, whilst the parking brake uses the same button movement for up-or-down lever movement, but also includes a hold or flick option for either a slow crawl or snap or jerk lever actuation. This snap or jerk lever action of the emergency brake was modelled on how an able-bodied driver would apply the emergency brake in a real life situation.

- ***Hazards***

The brake pedal attachment also has a button to activate the vehicle hazards while stationary. This is in anticipation of an emergency, while participant X foot would be on the brake pedal. It was also in answer to a request from Participant X as she found it difficult to apply the hazards, using the beeper system while driving.

- ***Secondary Control Functions***

The secondary control adaptations provided actuation of functions, such as indicators, and headlights and were controlled with the aid of a beeper system. The beeper unit was mounted against the centre console, within reach of Participant X left foot. The beeper system fed into the main controller, which controlled all secondary functions through the fuse box of the simulator, with additional feedback to the driver provided via a screen that was mounted in front of the radio panel.

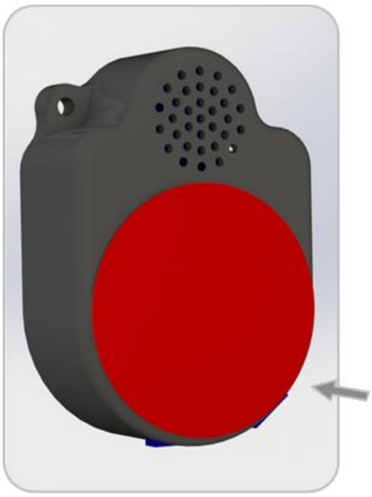

FIGURE 4.22: BEEPER BUTTON

(Author. 2013)

Participant X would press and hold the beeper button with her free leg / foot, whereupon the system would start beeping. Participant X had the number of beeps related to a given secondary function committed to memory, which enabled her to release the button once the beep count match the required function, although the feedback screen would also indicate the function to her. The following list gives the secondary control functions in relation to the number of beeps. These functions were adopted and adapted to suit Participant X original set-up in her vehicle.

Beep 1	=	Hooter / Horn
Beep 2	=	Left Indicator
Beep 3	=	Right Indicator
Beep 4	=	Head Light ON/OFF
Beep 5	=	Head Light Bright/Dim
Beep 6	=	Head Light Flashing
Beep 7	=	Front Wind Screen Water
Beep 8	=	Front Wiper Slow
Beep 9	=	Front Wiper Fast

FIGURE 4.23: SECONDARY CONTROL FUNCTIONS

(Author, 2013)

By powering down the main control for the adaptive system, all secondary control functions were routed through its normal buttons and stalks, allowing an able-bodied person to drive the vehicle in the normal fashion. This feature again conforms to the UD principles.

Low-Fi prototypes were manufactured, aiming to familiarise Participant X with the team and the design process. Prototypes were used to evaluate her interaction with the adaptive driving aids in the simulator. Ergonomic placement of the driving aids was chosen by involving Participant X in a fitment workshop. As the workshop was carried out, each step was explained to her to ensure that, as much as possible, she was kept involved in the design process.

4.3.5.2 Prototypes

With the challenges understood up to this point, a simulator shell was designed and constructed with the purpose of creating a realistic driver experience(See Fig 4.24). One constraint of the iDes simulator viewed at Stellenbosch was that the driver is in an open environment and thus is easily distracted by elements other than the activities involved with driving a car. Since the surrounding area is stationary while the vehicle moves on the simulator screen, the user is prone to simulator sickness. Because ~~of~~ the author had experienced simulator sickness within 5 minutes of using the simulator, a decision was made to create a realistic environment in which the user of the simulator would not be distracted by the outside environment. Participant X could not test-drive the simulator in Stellenbosch due to its limited usability. Apart from an able-bodied driver, the simulator could accommodate only quadriplegic drivers. What follows is the manufacturing process of the body shell for the simulator designed by a team selected according to the meta-design theory. The shell was built by a qualified artisan who also gave design input with regards to the manufacturing process.

FIGURE 4.24: SIMULATOR VEHICLE PLATFORM

(Author, 2014)

4.3.5.3 Joystick steering prototypes for the simulator platform

FIGURE 4.25: SIMULATOR STEERING JOYSTICK PROTOTYPE

(Author, 2013)

FIGURE 4.26: SIMULATOR STEERING JOYSTICK PROTOTYPE

(Author, 2013)

Understanding the functionality of a drive-by-wire steering, the team obtained and stripped a simulator steering wheel and pedal. It was found that the inner workings of the steering wheel could be used in the simulator with some hardware adaptations made. Since Participant X could not use a steering wheel, the adaptation required would be a joystick steering cup as the interface between the electronic hardware and the user. A rough prototype of the joystick steering cup was design and manufactured using plexi-glass (See figure 4.19). The interface between the user and the control interface was designed using a stacked template. With a laser cutter templates were created that were glued together hand finished to form the prototype. The control part of the joystick was manufactured using HDPE (See fig 4.18). This was the part that would remain the same as far as possible, the part that can change is the joystick cup.

FIGURE 4.27: LIMITING USER USING A STANDARD PC KEYBOARD

(Author, 2012)

During an informal observation session, Participant X was observed using a standard pc keyboard. This observation was considered an important part of the design process due to the button sizes used in a pc keyboard. An idea had come to mind that a foot keypad could be developed using the pc keyboard button sizes as reference.

FIGURE 4.28: CONTROL KEYPAD CONCEPT

(Author. 2013)

For the control key pad, a model was designed based on a pc keyboard which Participant X used on a daily basis. The keyboard F1 key determined the size of the key. Participant X stated that the size would be adequate. Along with input from the electrical engineer, the basic layout was determined according to various industrial keypad layouts. The basic control keypad layout was presented to Participant X in a graphic format.

FIGURE 4.29: KEYPAD PROTOTYPE

(Author, 2013)

After Participant X had reviewed the graphic representation of the foot control key pad, a prototype was produced using a CNC milling machine. The PCB's and buttons for the control pad, as well as the programming, was carried out by the mechanical and electrical engineering students.

FIGURE 4.30: CENTRE CONSOLE LED SCREEN PROTOTYPE

(Author. 2013)

Along with the control key pad a visual representation of selected functions was required. Since Participant X was used to a cell phone, as well as a desktop personal computer, it was decided in collaboration with the design team and Participant X , that a monitor would be used to give feedback on selected functions. This monitor would also be a touch screen due to the Universal Design aspect of the study. If a user with touch ability should use the simulator, the touch screen would function as both control key pad and visual feedback for selected functions. Thus, in such a case, the control keypad could be removed. The functions used in the simulator are the same as in a standard vehicle, but are not limited to these. The monitor, along with the control key pad, was developed to be the central control unit of the adaptive system developed for the simulator. All other adaptive aids required for driving would be plugged into this centre control unit. The foot pedals, amongst others, were considered part of the adaptive aids.

FIGURE 4.31: FOOT PEDALS AND SWITCH CLUSTER CONCEPT

(Author. 2012)

A pedal cluster used for simulators was obtained for the foundation of the prototype built. Using the pedal cluster in its standard form posed difficulties for Participant X. Consequently, a set of pedals was designed according to the dimensions of her own vehicle. Participant X reviewed the graphic representation and requested a hazard button along with the standard gearshift and emergency brake toggle buttons.

FIGURE 4.32: FOOT PEDALS PROTOTYPE

(Author. 2012)

After Participant X had provided the design team with input on the design:

‘would it be possible to add a hazard button to the brake pedal ?’

,a prototype was built and prepared for testing. Once all the adaptive aids had been produced in prototype form, an interactive fitment workshop was scheduled. The agenda for this fitment workshop was, firstly, to fit all the adaptive aids but, more importantly, to introduce Participant X to the ergonomics of the simulator and observe her as required by the PD and case study methods of research. Observing Participant X was an important part of the research as it would alert the author to any areas of concern and design changes required.

Foucault and Thomas (2011) had a similar approach towards triangulation in case study research, stating that we can only really understand something once we have looked at the case from different angles using different methods (Foucault, 1981). Consequently, what follows is the second part of a triangulation observation workshop. The findings of this fitment workshop were compared to the findings made while observing Participant X as she was driving her vehicle. This allowed for a more detailed set of design requirements to be established for a simulator.

TABLE 4.2: DATA FROM FITMENT INTERACTIVE WORKSHOP

FIGURE 4.26: MEASURING FOOT PEDAL BOX DISTANCE WITH PARTICIPANT X ASSISTANCE
(Author, 2013)

The foot pedal was placed in the simulator shell. Participant X was asked to provide the author with input regarding comfort, ability and ease of using the foot controls. The height and reaching distance were adjusted according to her input (Participant X , 2013).

Challenges:

During this fitment session Participant X raised a concern: 'the pedals are far apart ,its difficult when I change from using the throttle to braking' (Participant X , 2013).

FIGURE 4.27: PLACING THE SWITCH BOX
(Author, 2013)

After the pedals had been placed in a satisfactory position, the foot control keypad was held in position by the author to determine a suitable position. However, no ideal position could be established. Thus the author decided that an adjustable support would prove a valuable addition to the design.

Challenges:

The author observed that the prototype buttons would require some dust and moisture protection since a user would transfer sand from outside the simulator to the keypad when entering the simulator. Since the prototype was made of plastic it was also noted that a user might benefit from a sturdier design, as some of the buttons flexed out of position and did not function properly. This would mean that certain functions which should be activated by the keypad could not be carried out.

FIGURE 4.27: LIMITING USER VERIFYING THE READABILITY OF THE LED TOUCH SCREEN
(Author, 2013)

Along with the foot keypad controller, the LED touch screen was fitted, and the readability of the command screen was tested and approved by Participant X. She raised no concerns and showed some excitement as simulated functions, pointed out by her during the initial observation workshop, were used to test the display. The one function that stood out above all was the ability to control the AC unit, as this had been removed from her own vehicle to accommodate the adaptive steering aid.

After having tested the LED display, the secondary function beeper button was fitted and tested. It was noted that the button could be fitted directly to the upholstery centre console of the simulator shell.

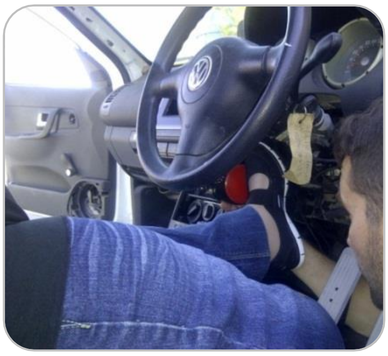

FIGURE 4.28: PLACING THE SECONDARY FUNCTION BEEPER BUTTON

(Author, 2013)

Challenges:

The author noted that the button was not accurately responsive to the user's input; the hardware inside the button needed to be reviewed by the electrical engineer.

FIGURE 4.29: CHECKING PLACEMENT OF THE JOYSTICK CONTROLLER

(Author, 2013)

The joystick steering actuator was placed in a comfortable position at Participant X shoulder and then marked on the door. The door was then reinforced to accommodate the added weight of the controller.

Challenges:

The weight of the joystick cup, as well as the length of the 2 'horns' were a concern to both the author and Participant X: 'The joystick horns are to high, I'm concerned about getting hurt when in an accident'. The height of the 'horns' and the general materials used for the joystick cup would have to be revised.

The preferred position of the joystick cup was transferred to the door by placing it under Participant X shoulder and marking the position and orientation on the door frame. Reinforcement brackets were attached to the door panel to accommodate the force exerted on the door when using the steering joystick.

FIGURE 4.30: CHECKING FITMENT OF THE JOYSTICK CONTROLLER
(Author, 2013)

Collecting data by way of observation was vital during the fitment workshop. Thus a third party was asked to make an audio visual recording for review after the fitment workshop. These procedures were carried out to ensure triangulation, as recommended by Thomas (2011). The aim of triangulation observation is to gain in-depth understanding as far as possible with regard to the adaptive driving aids designed for the simulator. As the data were collected, the second cycle of reflection could be carried out.

4.3.6 Cycle 2 - Reflect:

In this phase of Cycle 2 the team reflected upon the challenges faced during the observation prototype fitment workshop. The design challenges were addressed by arranging the data in a table, reviewing them, and noting alterations to be made to the adaptive aids designs. In the light of these alterations another fitment workshop was considered in which the adaptive aids would be installed in the simulator and an actual driving test carried out. This would form the last PD cycle.

TABLE 4.3: ADAPTIVE AID PROTOTYPE ITERATIONS

FIGURE 4.31: INITIAL JOYSTICK CUP PROTOTYPE

(Author, 2013)

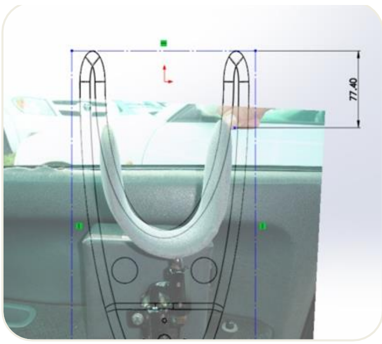

FIGURE 4.32: HEIGHT DIFFERENCE

(Author, 2013)

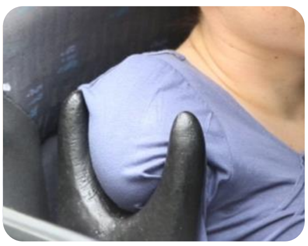

FIGURE 4.33: LIGHTER JOYSTICK CUP

(Author, 2013)

Challenges:

The weight of the joystick cup, as well as the length of the two ‘horns’, were a concern for the author as well as Participant X. The height of the ‘horns’ and general materials used for the joystick cup would have to be revised. The preferred position of the joystick cup was transferred to the door by placing it under Participant X shoulder and marking the position and orientation on the door frame. Reinforcement brackets were attached to the door panel to accommodate the force exerted on the door when using the steering joystick.

Design iteration:

Height: The actual height difference between the original joystick cup used by Participant X and the new design was 78 mm. Thus the design iteration called for a shortening of the joystick cup ‘horns’.

Weight: The joystick cup material was changed to carbon fibre. This allowed for strength and light weight.

Challenges:

The author observed that the prototype buttons would require some dust and moisture protection since the user transferred sand from the outside of the simulator to the keypad when entering the simulator. Since the prototype was made of plastic it was also noted that the user might benefit from a sturdier design, some of the buttons flexed out of position and didn't function properly and thereof or certain functions activated by the keypad couldn't carried out.

FIGURE 4.34: INITIAL FOOTPAD CONTROLLER PROTOTYPE

(Author, 2013)

To avoid soiling the foot control buttons, standard dust and waterproof buttons were obtained from a supplier and then used to alter the design of the footpad controller without altering the layout or general dimensions.

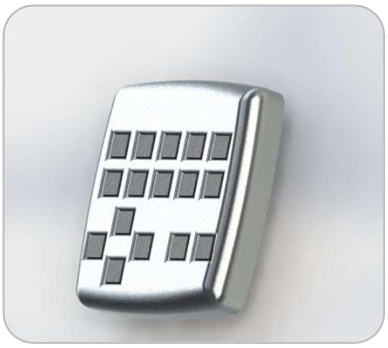

FIGURE 4.35: IMPROVED BUTTON DESIGN

(Author, 2013)

To address the challenge of mounting the footpad controller, an adjustable mount was designed and fitted to the pedal box.

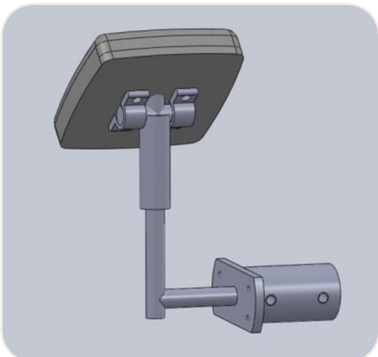

FIGURE 4.36: FOOT PAD CONTROLLER ADJUSTABLE MOUNT

(Author, 2013)

FIGURE 4.37: ORIGINAL MOUNTING POSITIONS OF PEDALS

(Author, 2013)

As mentioned earlier, the distance between the pedals was a concern for Participant X . These additional mounting positions were added to the aluminium pedals.

FIGURE 4.38: ALTERED PEDAL POSITION WITH ADJUSTABLE KEYPAD

(Author, 2013)

The pedal box now features pedals that are adjustable as well as an adjustable keypad

Table 4.3 summarises the design alterations required for this cycle of the PD design process. As part of the 3rd and last PD cycle, another observation workshop was planned. The following section will elaborate on Cycle 3 of the PD process.

4.3.7 Cycle 3 - Planning:

The first phase of this cycle consisted of planning the last iteration for the simulator design: deciding on the processes to be used to evaluate the simulator's performance within the Universal Design case study guidelines. Participant X would be asked to use the simulator for an extended period of time, and filming would be done with a galaxy tablet. Reviewing the data collected in Cycle 2 and making design iterations accordingly was part of this planning cycle. The table below illustrates the last design iterations before fitting the adaptive aids to the simulator shell.

FIGURE 4.39: REVISED JOYSTICK STEERING

(Author, 2013)

Description:

The final joystick cup design features a shorter 'horn' length. The materials used to manufacture the cup are carbon fiber and aluminum on a plastic base. This allowed for a light-weight yet durable cup.

FIGURE 4.40: REVISED JOYSTICK STEERING

(Author, 2013)

The joystick cup shape was chosen by mimicking Participant X original joystick shape, thus ensuring a comfortable fit.

Participant X tested this new joystick cup and was satisfied with the revised version: 'This cup is much better than the previous one'.

FIGURE 4.41: FOOTPAD CONTROLLER

(Author, 2013)

Description:

The last iteration on the foot keypad controller consisted of changing the outer shell shape by giving it rounded corners. The author observed that Participant X would slide her foot from the accelerator pedal onto the touchpad; thus the rounded shape design was more user-friendly.

Water and dust-proof rated buttons were laser-edged and used in this controller to ensure longevity.

FIGURE 4.44: FOOT PAD CONTROLLER ADJUSTABLE MOUNT

(Author, 2013)

Along with the button and general shape alterations, the footpad controller was fitted with an adjustable mount. Which allowed Participant X to position the controller within 3 mm of the acceleration pedal, thus ensuring a quick operation of both.

FIGURE 4.43: ORIGINAL MOUNTING POSITIONS OF PEDALS

(Author, 2013)

As mentioned above, the distance between the brake and accelerator pedals proved to be a challenge to Participant X . This challenge was addressed by changing the mounting holes in the pedals, allowing for a closer mounting position to one another.

FIGURE 4.42: PEDAL BOX WITH IMPROVE PEDAL MOUNTING POSITIONS AND ADJUSTABLE KEYPAD MOUNT

(Author, 2013)

As can be seen, the completed pedal box features an adjustable footpad controller within close proximity of the accelerator pedal and a closely mounted brake pedal.

4.3.8 Cycle 3 - Act/ Observe:

An observation workshop was scheduled at the location where the entire development of the simulator had taken place. Participant X was familiar with the setting; thus no concerns were raised with regard to unobtrusive testing of the simulator. For this step, Participant X was observed using the simulator, with the latest version of the adaptive aids installed, for an extended period of time. She was asked to comment on the experience of using the simulator.

FIGURE 4.45: OBSERVING THE FIT OF THE JOYSTICK STEERING CUP AND FUNCTIONALITY

(Author, 2014)

The steering joystick used in the simulator was test-fitted to Participant X . She could move the joystick cup within the full range of movements required to steer the vehicle.

FIGURE 4.46: CHOOSING THE SIMULATOR DRIVING ENVIRONMENT AND VEHICLE

(Author, 2014)

Participant X noted that the cup shape fitted her very snugly. While she tested the joystick steering, she was also distracted by observing the footpad controller, foot pedals, as well as pedal switch cluster and red beeper button. This was a satisfactory observation due to her comment regarding the familiarity of the simulator com-pared with her own vehicle. In sequence all the controls were tested and evaluated. Unfortunately, only certain controls could be documented due to IP protection.

FIGURE 4.47: USING THE KEYPAD

(Author, 2014)

Participant X chose specific functions by means of the footpad controller, using her right foot covered in a sock. The buttons of the controller had been recessed to allow her easy location without visual confirmation. This proved to be a success since Participant X quickly memorized the button layout and was able to use the controller without breaking eye contact with the simulator screen.

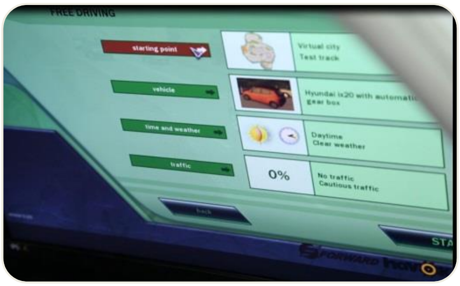

FIGURE 4.48: CHOOSING THE DRIVING ENVIRONMENT

(Foulkes, 2015)

A driving instructor chose the driving environment with input from Participant X who could choose various vehicle models, set the color of the vehicle, etc.

A learner number plate could be selected as well. Features, such as weather and road condition, along with traffic and pedestrian density allowed for a realistic driving experience, as well as choices of different levels of training.

FIGURE 4.49: REVERSING AND PARKING USING ALL THE FUNCTIONS, AS WITH A CONVENTIONAL VEHICLE

(Foulkes, 2015)

The first driving exercise which Participant X carried out was to reverse the vehicle. She had to select a gear by using the pedal switch cluster, release the emergency brake and pull out of the parking space in reverse.

The pedal switch cluster was designed to simulate a tip-tronic gear change system, meaning that a user would only have to tap the gear switch to move the gear level to the next position. This design improvement over the original system proved to be a success, according to Participant X , since she could now concentrate on driving rather than worrying about selecting a desired gear position. The emergency brake worked on a similar principle. Participant X could activate and deactivate the emergency break by the push of a button.

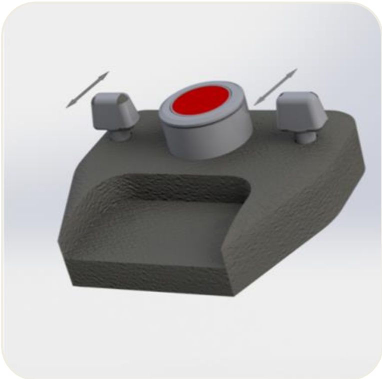

FIGURE 4.50: GEAR AND EMERGENCY BRAKE SELECTION

(Author, 2014)

After about 15 minutes of Participant X using the simulator, the author asked whether she experienced any nausea or disorientation. The author was surprised to hear that she did not experience such sensations. Although the exact cause for simulator sickness was not researched as part of the study, the author assumed that designing the simulator as close to a realistic vehicle as possible would limit the simulator sickness effect. This design choice would benefit from further study

FIGURE 4.51: REALISTIC DRIVING ENVIRONMENT

(Foulkes, 2015)

During the simulator driving exercise, Participant X also used the LED touch screen as visual confirmation of functions selected. The functions selected were those related to driving.

FIGURE 4.52: DRIVER USING THE LED TOUCH SCREEN AS VISUAL FEEDBACK WHEN SELECTING FUNCTIONS WITH THE KEYPAD CONTROLLER

(Foulkes, 2015)

FIGURE 4.53: FOOT PAD CONTROLLER AND PEDALS

(Author, 2014)

Functions selected with the keypad could be de-activated by the LED touch screen or keypad controller. The functions included headlights, air-conditioning, starting/shut-down of the vehicle engine and hazards. These are just a list of functions selected for demonstration purposes. Any number of functions could be added to the controller at a later stage as required. This is one of the unique features in this simulator, allowing it to be considered, by the author, to be a Universal Design product.

FIGURE 4.54: REALISTIC SIMULATOR ENVIRONMENT DUE TO A VEHICLE BODY SHELL

(Foulkes, 2015)

As mentioned earlier, the body shell of the simulator represented a real-life vehicle. Darkened windows prevented the user from being distracted by the outside environment. Once the driving instructors have set up the driving exercise, they could leave the vehicle and observe from the back without hindering the user.

FIGURE 4.55: OPEN VIEW FROM THE BACK FOR INSTRUCTOR OBSERVATION

(Foulkes, 2015)

An open view from the back of the simulator allows the driving instructor to have a full view of the simulator screen as well as the user. This benefits the users' driving experience since they can focus on the task without being intimidated by the presence of a trainer. According to case study research, this also allows for an unobtrusive observation of how the user operates the simulator controls in case of further study opportunities.

4.3.9 Cycle 3 - Reflect:

This step in the PD process consisted of final thoughts on the outcomes of the simulator design. The findings from all three reflection phases of the PD process were formulated into key themes which are further discussed in Chapter 5. Chapter 5 thus acts as a summary of chapter 4.

5. CHAPTER FIVE: KEY THEMES

5.1 Introduction

In this chapter, key themes that emerged during the design of the simulator will be discussed. Prominent among these themes, as noted during an inductive data analysis exercise, are the following: the role and impact of a limiting user and the inter-personal relationships that influence a participatory project.

Throughout the design process, important questions were considered whilst working with a limiting user. Did working with a limiting user yield a reliable user scenario? What impact did personal character and personality have on the process? What challenges were experienced when the limiting user changed her mind on a regular basis? Universal Design was the framework within the process as it promotes usage across as large a usage group as possible. Did working with a limiting user affect this design framework? Central to the final design solution was the concept of modularity which transcends the single limiting user requirements to contribute to a more universal design.

The second theme reflected upon the influence of inter-personal interactions within a trans-disciplinary research group. Meta-design may have broken down barriers within the design team, but the members of each discipline still embraced their own specific language and terminology that caused interaction barriers. These barriers were overcome by the individuals' attitudes towards the goal of designing a simulator. The meta-design approach enabled team members to increase their own professional capacity. Understanding each team member's contribution towards the success of the project, and what impacted the interaction throughout the process, is important as it helps define the functioning of a meta- design team.

5.2 Participatory Design and a Limiting User

5.2.1 Is the limiting user a real scenario?

During the PD process with Participant X, the author was aware of how one person representing a bigger group of people could dictate or guide the outcome of the end product which, in this case, was a simulator. Refer to section 2.5: Ergonomics for the differently abled (Limiting User) for clarification on the limiting user. Figure 2.1 pg 26 illustrates a pyramid of people with different physical abilities ranging from people who can perform all the ADLs to people who can perform only a limited number of ADLs.

Although the PD process was carried out with relative ease, the author questions the input obtained by means of a limiting user approach. During the 3rd cycle of the process, Participant X , representing the limiting user, changed her mind regarding the preferred position of the steering joystick device and how it should function. The people involved were the author, limiting user and the electrical engineer. During Cycle 2 of the PD process the fitment of the joystick steering device was carried out and the functionality had been discussed with Participant X . She chose a preferred position. However, during the 3rd cycle of the PD process, Participant X asked that the steering joystick be repositioned as it was no longer comfortable.

As mentioned in Chapter three, Yin et al. (2006) discuss this occurrence of conflicting data obtained from a person during a case study. When conducting a field interview, the results might be in conflict with those from an earlier interview. The researchers recommend that such data can be resolved by collecting more data: the interviewer can turn to a third party for more information or re-interviewing the first participant.

The challenge of conflicting data was, however, resolved by comparing the notes from Cycles 2 and 3 of the PD process and allowing Participant X to use the simulator for a longer period of time before the observation process was continued by the author. The result was that Participant X was comfortable using the joystick steering device for an extended period of time without further concern. During the inductive data analysis process, the author reviewed the exact events which occurred during the conflicting data observance: Participant X had moved the vehicle seat further back than previously recorded. Since the steering joystick was mounted to the door frame, the position of the driver seat relative to the joystick was an important part of the ergonomics of the adaptive steering aid. Thus, although a conflict of data had been observed, the result was still satisfactory for all practical purposes.

The author noted that due consideration should be given to the test environment while doing user testing. To achieve triangulation, the driver seat was set to the new position and further testing was done on the position of the steering joystick. Participant X handled the process of further observation with a positive attitude. Thus one might ask how much of the success of involving a limiting user in a PD cycle is dependent on the personality or character of the participant?

5.2.2 What impact did personality and character have on the design process ?

As discussed, the occurrence of conflicting data while observing Participant X led to a further informal interview with her which she handled without any complaints. This was noted as a key theme for discussion as the observation workshops were normally time consuming; yet Participant X participated with eagerness.

Judging how much influence character and personality exerted on the progress of this project is difficult since the primary focus of the study was the building of a simulator. Yet, during the time spent observing Participant X the author noted the level of acceptance, the positive attitude she demonstrated towards the team members, and the patience with which the process was approached on a daily basis. This proved the point that her character enabled her to accommodate the design team in her personal space. The following quote from her background sheds light on the kind of personality and character she has (Participant X , 2016:1):

> "A supportive family, access to mainstream schooling and my determined personality helped me to achieve independence and a positive outlook on life. I was born without arms and with shortened legs (the medical term is Phocomelia). While there was no medical explanation for my disability, I was fortunate that my parents were determined to have an optimistic view for my future…. I attended mainstream schooling and learnt to write with my right foot. I was a happy and outgoing child, taking part in many activities at school including swimming, tennis (I held a racket between my chin and shoulder!) and drama. I did well academically and was always self-motivated – I do not think my parents ever had to tell me to do my homework!"

This statement expresses her attitude towards challenges. Pickens (2005) describes attitude as a mind-set or a tendency to act in a particular way due to both an individual's experience and temperament. Our attitude helps us decide how we perceive a situation, and thus also how we behave towards the observed situation (Pickens, 2005). Participant X attitude played an important part in the success of the simulator development for this dissertation because, in representing the wider UD group during the simulator design and testing, she was friendly, helpful and open to suggestions from the author. These suggestions included changes to how she used to operate her own vehicle compared to the simulator. One such change was the functioning of the steering joystick. The simulator system was designed on a drive-by-wire system in which all the adaptive aids are connected to the main controller by means of electric wires which relay the inputs of the user to the simulator. Participant X vehicle used for daily commuting featured a steering joystick the operation of which was based on hydraulics. This means that the feel of the joystick in the simulator was different yet performed the same function. The author believes that, because of Participant X positive attitude, this new drive-by-wire steering joystick could be tested intensively. If Participant X had not been willing to endure the on-going testing, the adaptive steering joystick might not have been developed to the point where it could be used in the simulator.

5.2.3 What challenges did Participant X regularly changing her mind or ideas present?

Although Participant X had a positive attitude towards the PD process carried out in the research, observing her brought to light her indecisive nature.

During the 1st and 2nd stage of the PD cycle, a system design was formulated which would require her to activate the emergency brake by means of the foot pedal switch button. The activation of this button would work on the same principle as a tip-tronic automotive system. A tip-tronic system changes the gear selected by pushing or pulling a button; the gear would then move to a pre-programmed position. The emergency brake worked in the same fasion, however Participant X was unclear how quickly the system should activate the handbrake when she pulled the button.

Another example concerned the ergonomic placement of the steering joystick. As the seat of the simulator emulates that of a real vehicle, it provides the user with various positions of driving, the aim being a fatigue-free and comfortable drive. The steering joystick, however, was mounted on to the right-hand door of the simulator and, once mounted in position, was not meant to be moved. The author noted on various days during PD Cycles 2 and 3 that Participant X requested the position of the steering joystick to be altered for greater comfort. As this raised a concern with regard to practical use of the simulator on a regular base, the author addressed this matter with an anthropometrics professional. Due to the limited time available for the study the author recommends further research into the design and placement of the steering joystick. The author noted that a design is never completed; as one challenge is addressed, other challenges are created. ‘The only thing that is constant is change’ (Robinson, 2004:1). The author is of the opinion that, according to this quote believed to have been said by greek philosopher Heraclitus, design will never be complete. From a product marketing point of view, as well as considering the user-perceived value of a product, this constant change should be embraced in design (Gautam & Singh, 2008).

5.3 UD Product Design

5.3.1 Does a limiting user complement UD design?

As part of the design requirements and planning a limiting user approach, as well as a Universal Design approach, was chosen. This dissertation was conducted with the aim of delivering a product that would benefit as many people as possible, according to UD. Using a limiting user within a case study research method seemed contradictory to the UD guidelines. Defining Universal Design suggests that all elements and spaces be accessible and usable by all people to the greatest extent possible (Dalcher, 2006). This is carried through in all aspects of design by means of thoughtful planning with the focus on accessibility (Design, 1998:3). The Centre for Universal Design, NC State University, laid down guidelines for the practical application of Universal Design by formulating seven principles of Universal Design (Aslaksen et al., 1997): (see page 38)

During the PD process, the author experienced a conflict between the 'limiting user' approach and the UD guidelines. Participant X requested that the brake and accelerator pedals used in the simulator be adjusted closer to one another. The reasoning was a quick transfer from the accelerator to the brake pedal, which was understandable from the user's point of view (Participant X, 2015). However, with the UD design principles in mind, the author chose to accommodate Participant X only up to the point where the design iteration would complement the UD requirements. Although the limiting user had an important role to play in assisting the author and design team to develop an adaptive system, the UD criteria also played an important role in the choices made by the author during this study. The author learned that compromise is required in design.

5.3.2 Modularity as a vehicle for Universal Design?

As Universal Design received priority in this dissertation, the 'limiting user' approach served the purpose of designing the adaptive system. The interface, however, featured certain parts specific to the limiting user. This posed a challenge for other persons who would use the simulator in the future. To overcome the challenges of customised interfaces, a modular approach in the design of the adaptive system allows as many individuals as possible to use the simulator. The adaptive system consists of a main controller and LED screen that communicate with the simulator hardware and software; all the other adaptive controls are removable, if, however, an adaptive controller different to the ones available should be required, such a controller would need to be custom designed for the system. There were, however, other benefits to the simulator apart from developing adaptive driving aids.

5.3.3 Training beyond just a simulator?

During the construction of the simulator, the author noticed Participant X interest in new adaptive aids developed for the simulator. The author thus questioned the function of the simulator as just a training platform for automotive drivers. Studies done at the University of Alabama found that simulator training goes beyond just training or rehabilitation as a given exercise (Roenker et al., 2003:218). During the process of using the simulator, the author became aware that each team member, including Participant X , gained experience in communicating with one another. This observation was made during the full course of the PD cycles. During the first PD cycle, the engineers involved would rarely communicate with Participant X . Planning was conducted separately. As the project evolved, the engineers in particular took part in conversations with Participant X . What was unique about these conversations was the use of terminology specific to each discipline and how the adoption of different terminologies assisted in breaking communication barriers. An occurrence of change of terminology happened during Phase 3 of the PD cycle when an electrical engineering student conversed with Participant X directly regarding the functionality of the steering joystick. Participant X took part in the conversation giving feedback to the engineer.

The author observed the engineer use layman’s terms instead of engineering terms. This enabled Participant X to take part in the dialogue with relative ease. Apart from the communication limitations the team members involved were not necessarily professionals in their field of study. Thus the simulator design and construction provided a platform for the bachelor’s degree students involved to gain valuable practical experience before entering the corporate career environment. Furthermore, this project also created an opportunity for network building of skilled professionals. This study showed that, although the simulator was meant to be a product for driver training, various other gains were made concerning multi-disciplinary teamwork, professional capacity building and practical experience for the students involved.

5.4 Meta-Design and the Team

5.4.1 Language barrier within different disciplines

Within each discipline, individuals learn to use the terminology related to that discipline. The reasoning behind this practice is to ensure effective communication as part of the discourse of the given field of study. Pellmar and Eisenberg (2000) observe that scientists trained in a specific discipline learn to use terminology specific to their field of study and adopt the analytical and methodological constructs that grew with the discipline. This practice is meant to develop professional socialisation but can present obstacles to inter-disciplinary projects, such as conducted in this research project (Pellmar & Eisenberg, 2000). Somerville (1998:43) states that

> 'We speak the language of our discipline, which raises two problems: first, we may not understand the languages of the other disciplines; second, more dangerously, we may think that we understand these, but do not, because although the same terms are used in different disciplines, they mean something very different in each.'

Examples of this occurrence in design theory were when the terms meta-design, limiting user and universal design were used to describe specific concepts embedded underpinning the theoretical framework of this research. During the practical design exercises, these terms were not always used because of the inter-disciplinary language barriers.

As stakeholders from various disciplines took part in the design of the simulator each used their own terminology and framework of understanding on a daily basis. Often, during team meetings, terms used had to be explained and discussed. As the study progressed, the author observed team members communicating more freely without using the language of their discipline. All team members made an effort to use a commonly understood language. One such instance was evident during the 3rd PD cycle when an engineer conversed with Participant X during the use of the simulator platform. The conversation took place without any use of discipline specific knowledge. (See Figure 5.1.)

FIGURE 5.1: ENGINEER IN CONVERSATION WITH LIMITING USER

(Foulkes, 2015)

5.4.2 Attitude towards team members

As the language used by different team members changed the author also noted a change in attitude ŧ among team members. Attitude is a mind-set or a tendency to act in a particular way due to both an individual’s experience and temperament (Pickens 2005). Pickens elaborates on the forming of attitudes in his book ‘Attitudes and Perceptions: Learning Outcomes’. He maintains that attitudes are formed as a result of direct experiences with people, modelling others and learning. These points complement what the author observed during the entire period of this study. Cognitive experiences affect the attitude of the person who has the experiences and is also moulded by his emotional make-up (Pickens 2005). According to Pickens, one can provide a team member from a different background with enough information to understand a new situation and be able to make an informed choice. An example of this occurred at the beginning of the project during the first planning phase. The author observed a professional distance among the members of the team. As a designer, the author had to mediate between team members. According to Pickens, this mediation process assists the change in attitude within the team. The engineering team would focus on the tasks and functions related to their discipline and would challenge statements related to the product that seemed to contradict their experience and knowledge They could not practise understanding of a team member from a different disciplinary backgrounds with his unique point of view, and vice versa. As the project progressed, the somewhat intolerant attitude towards Participant X and other stakeholders changed as each became aware of the role and importance of the other disciplines. The author believes this awareness was created due to the time spent working together as a meta-design team (Fischer, 2003:2). As the study came to an end the author concluded that its success was to be attributed to the different disciplines working together, communicating with less restraint and better understanding, each performing a function towards building a product that involves more than just one discipline. A suggestion for further research would be the challenge of creating ideal conditions for professional attitude change to take place.

Development of professional capacity

In this dissertation, professional capacity is used with reference to the skills growth that took place because of the research collaboration in a multi-disciplinary team. According to Thomas Humphrey (1999), professional capacity building is the process of developing a new skill or enhancing existing knowledge that is required to perform a task successfully. Although the aim of this dissertation is to investigate simulators for differently abled drivers, professional capacity building happened as a result of using a meta-design approach (Humphrey, 1999). From the author's point of view, the stakeholders who took part in the project grew in professional capacity because of the diverse nature of the team. By definition, meta-design teams or multi-disciplinary teamwork is a collaboration of researchers with expertise in different fields. Pride in one's own discipline can lead to a lesser view of other disciplines (Wilbanks, 1986). A meta-design team can work together, provided each stakeholder or team member understands and appreciates the value and limitations of his or her own discipline, as well as those of the disciplines of other team members (Donaldson, 1999; Pellmar & Eisenberg, 2000).

This appreciation of value and limitations became evident as vital teamwork developed during the PD process of this project. The engineers learned to appreciate Participant X input. During the simulator design process she was exposed to the extent of detailed engineering necessary to make a product function correctly. Each member gained experience and took with him or her a better understanding of a UD product designed and constructed by a meta-design team practising PD by means of a case study research method.

5.5 Summary

Several key themes were noted during the inductive data analysis phases of Chapter four. One theme relates to the relationship between PD and the limiting user. Although conflict in research outcomes was evident, a satisfactory result was achieved by further research. Part of the success of using a limiting user for research can be described to personality and character. The attitude of the limiting user was a positive contribution to the research process and its positive outcome. Participant X did, however, change her mind on occasion which put strain on the design process. The design process was carried out by using a Universal Design approach with a limiting user, and thus, when the limiting user's input was in conflict with the UD guidelines, the latter were prioritised.

Another theme concerns the modular approach, also part of the UD guidelines/framework, which was taken with the simulator design. Modularity, therefore, became a vehicle for UD in this project. Although the study was carried out with a limiting user, modularity allowed for a simulator platform that could be used for a variety of differently abled drivers. This would be achieved by changing the adaptive control used in the simulator.

A further theme relates to the nature of the research which was based on a meta-design team approach. Although a challenge was observed with regard to discipline- specific language barriers, the team functioned well because of a change in attitude once the importance of a multi-disciplinary team was understood. Due to revised attitudes and a multi-disciplinary team approach, the simulator has contributed valuable insights and knowledge towards the design of simulators for differently abled learner-drivers, as well as an enriched/expanded professional capacity of the stakeholders.

6. CHAPTER 6: CONCLUSION AND RECOMMENDATIONS.

6.1 Introduction

This chapter will discuss the conclusion, contributions towards Universal Design in Simulators and areas of further study as identified in this dissertation. Contributions of the study include a methodological combination of UD principles and case study parameters to form a UD Case study approach. The conclusion will explore the main design findings, as well as the implications of the key themes noted in Chapter 5. The key themes are:

- **PD and a Limiting User**
  - Is a limiting user a real scenario?
  - What impact did personality and character have on the design process?
  - What challenges were experienced with the limiting user changing her mind or ideas on a regular basis?

- **UD Product Design**
  - Does a limiting user compliment Universal Design?
  - Modularity as a vehicle for Universal Design?
  - Training beyond just a simulator?

- **Meta Design and the Team**
  - Language barrier among different disciplines.
  - Attitude towards team members?
  - Development of professional capacity?

Not all areas related to the key themes listed above could be addressed; thus limitations, as well as recommendations for further study, are presented for consideration. The dissertation map key below illustrates the 3rd cycle of the case study research, revisiting the purpose and approach towards future studies.

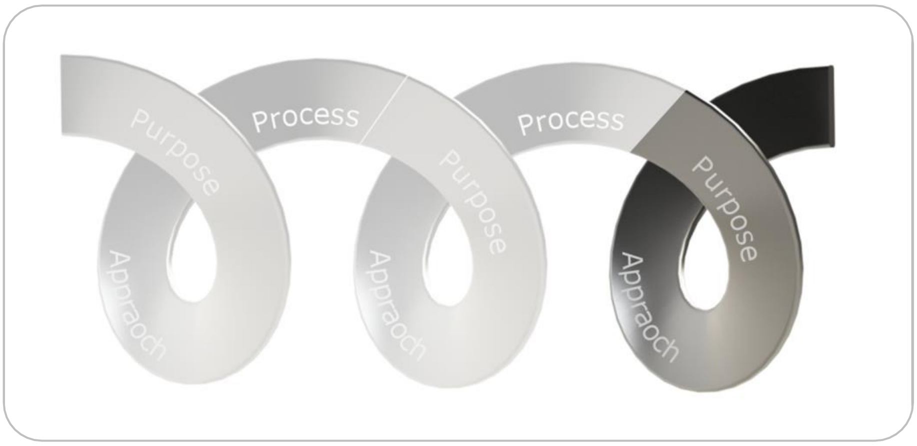

FIGURE 6.1: DISSERTATION MAP KEY

(Designed by the author according to findings by Thomas, 2011)

6.1. Conclusions

In 2015, Swanepoel, an occupational therapist at USeBenza Assessment Centre (Stellenbosch University) invited the author and Participant X to the launch of a simulator that could accommodate differently abled drivers. The challenge, however, was that the simulator could accommodate only paraplegic drivers. Classen, a professor and director at the School of Occupational Therapy (Western University, Ontario, Canada) gave a lecture on the use of simulators for rehabilitation purposes. During this lecture Classen pointed out that one of the challenges when using driving simulators was that a user could suffer from simulator sickness in the case of extended use. A, although Classen mentioned simulator sickness no cause for these symptoms was clarified (Classen, 2015). (See page 64, Figure 4.16).

After the presentation, the author and Participant X attended a demonstration of the simulator. The author was allowed to operate the simulator and established it had limitation with respect to the level of physical disability it could accommodate. The simulator could accommodate an able bodied driver and a paraplegic driver. Driver limitations highlighted the need to develop a simulator based on a Universal Design criterion, according to the 7 guidelines formulated by the Centre for Universal Design (Aslaksen et al., 1997). To be able to develop and build a UD based simulator, various stakeholders from different disciplinary backgrounds needed to give input on the project. A multi-disciplinary team, made up of a limiting user, occupational therapist, anthropometrics and ergonomics specialist, mechanical and electrical engineers, as well as a product designer (the author), was needed.

Research was carried out in the form of PD interactive workshops in which the limiting user set the bench mark for the simulator and adaptive aids design, the result of which answered the research questions as defined at the beginning of the research process. Through the process of answering the main research question contributions were made in the field of Participatory Design and Meta- Design practice, as well as towards the body of Universal Design knowledge. These include the final simulator and components, field notes and an initial review of the practice of working with a limiting user, as well as methodological contributions grounded in participatory practice.

6.2. Contributions

6.2.1. Product

FIGURE 6.2: PARTICIPANT X ABOUT TO USE THE SIMULATOR

(Foulkes, 2015)

Figure 6.2 showcases the first fully UD simulator designed and built in South Africa for differently abled learner-drivers. The simulator platform is based on a modular design to incorporate as many such learner-drivers as possible. The adaptive control fitted to the simulator can be altered to suit various disabilities. The simulator also allows for extended use without experiencing simulator sickness, as tested by Participant X.

Looking at the differently abled driving community, the challenge of designing such a simulator translated into the following considerations: Can a simulator be developed for differently abled drivers to assist in driver training in South Africa? More specifically, when designing a simulator for the disabled, which product and automotive factors influence the adaptation of assistive controls? When considering the adaptive control system, which contextual factors influence the use of such a system? How can the simulator be developed, applying the 7 Universal Design criteria? Table 6.1 is a description of the workings of the simulator in more detail. Table 6.1 also lists the challenges Participant X faced while driving her own vehicle as well as the design interventions that address these challenges. Figure 6.3 is an overview of the adaptive aids as an add-on system to the simulator. These add-ons conform to the 7 UD criterion and enabled differently abled drivers like Participant X to train in the simulator.

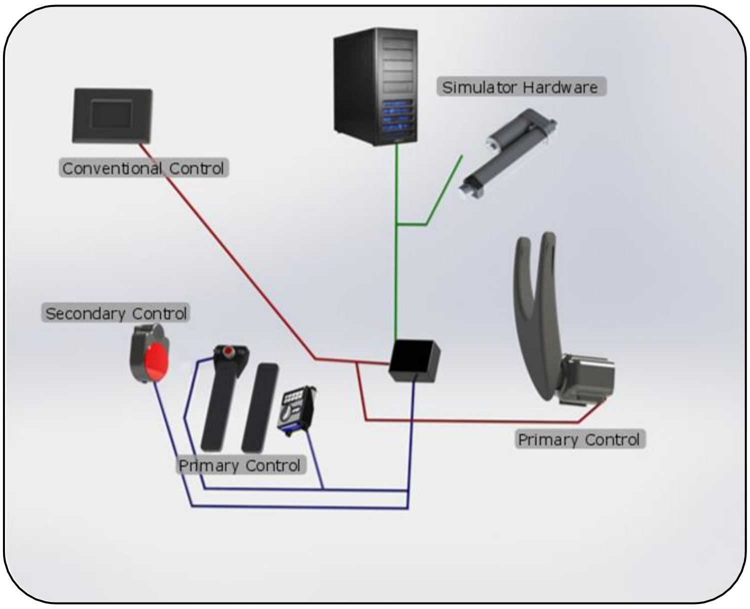

FIGURE 6.3: MODULAR ADAPTIVE SYSTEM

(Author, 2015)

Table 6.1 illustrates the product contribution as observed by the author while the limiting user drove the simulator in a pre-set environment. Table 6.1 describes in detail how each adaptive aid functions.

TABLE 6.1: CONTRIBUTIONS TOWARDS SIMULATOR DESIGN

FIGURE 6.4: SOFTWARE FEATURES

(Foulkes, 2015)

The software used in the simulator allows trainees to customize their training. A driving instructor chooses the driving environment with input from the trainee. The latter can choose various vehicle models, set the colour of the vehicle.

A learner number plate could be selected as well. Features such as weather and road condition along with traffic and pedestrian density allow for a realistic driving experience, as well as different levels of training.

- Equitable use (fair and impartial)
- Flexibility in use
- Simple and institutive use
- Perceptive information
- Tolerance for error

FIGURE 6.5: REALISTIC DRIVING ENVIRONMENT

(Foulkes, 2015)

No simulator sickness is experienced by the driver during training. Although the exact cause for simulator sickness was not researched as part of the study, the author assumed that designing the simulator as close to a realistic vehicle as possible would limit the simulator sickness effect.

The exterior as well as the interior of the simulator imitate a real vehicle. Thus as many features as possible are incorporated in the simulator construction.

FIGURE 6.6: REALISTIC DRIVING ENVIRONMENT

(Foulkes, 2015)

FIGURE 6.7: INSTRUCTORS VIEW FROM THE BACK OF THE SIMULATOR

(Foulkes, 2015)

The body shell of the simulator represents a genuine vehicle. Darkened windows prevent the user from being distracted by the outside environment. Once the driving instructor has set up the driving exercise s/he leaves the vehicle and observes from the back without hindering the user.

- Equitable use (fair and impartial)
- Simple and institutive use
- Tolerance for error
- Size and space for ease of approach in use

Joystick steering

FIGURE 6.8: JOYSTICK STEERING

(Foulkes, 2015)

The author noted that the joystick cup shape fitted Participant X snugly. While she tested the joystick steering she could also operate the footpad controller, foot pedals, as well as the pedal switch cluster and red beeper button. This proved to be a satisfactory outcome as Participant X commented regarding the familiarity of the simulator compared to her own vehicle (Participant X , 2015). Unfortunately, only certain controls could be filmed due to intellectual property protection. The joystick adaptive aid adheres to the following UD criteria:

- Tolerance for error

This is achieved via the design of zones in which the joystick can be used. (Chapter 4: Actuating the steering with the joystick)

- Low physical effort

Low physical effort is possible due to the lightweight carbon fibre design of the joystick cup.

- Simple and intuitive use

As the joystick is moved, the user has visual feedback from the steering wheel turning direction which allows for intuitive use of the joystick.

- Flexibility in use

Although not used in this study, the joystick steering is designed so that different cups or actuator interfaces can be fitted, should a user prefer a different interface.

FIGURE 6.9: KEYPAD CONTROLLER AND LED SCREEN

(Author, 2015)

Details of the adaptive control: Main controller, LED screen and keypad

During the simulator driving exercise, Participant X used the LED touch screen as visual confirmation of functions selected. These were functions related to driving and could be de-activated by means of the LED touch screen or keypad controller. The functions included headlights, air-conditioning, starting and shutdown of the vehicle engine and hazards. These are just a list of functions selected for demonstration purposes; any number of functions could be added to the controller as required at a later stage. This was one of the unique features on the simulator, allowing it to be considered, by the author, a Universal Design product.

This part of the adaptive system adheres to the following UD criteria:

- Equitable use (fair and impartial)
- Flexibility in use
- Perceptive information
- Tolerance for error
- Low physical effort
- Size and space for ease of approach

Keypad controller description and functioning

The user can activate specific functions by means of the footpad controller using the right foot covered in a sock. The buttons of the controller are recessed to allow the user easy location without visual confirmation. This proved to be a success since Participant X quickly memorised the button layout and was able to use the controller without breaking eye contact with the simulator screen.

Touch screen description and functioning

FIGURE 6.10: TOUCH SCREEN

(Author, 2015)

The LED touch screen provided Participant X with feedback on any function selected using the keypad. As the LED screen is touch-sensitive, a trainee or instructor could also activate functions or, in the case of a emergency, shut down the simulator.

Pedal box and keypad

FIGURE 6.11: PEDAL BOX AND ADJUSTABLE KEYPAD

(Author, 2015)

The pedal box used in the simulator is removable, as are all the adaptive controls in the simulator. The spacing between the pedals can be set according to the user's request. The keypad used to select functions is dust- and waterproof, as well as adjustable for comfortable operation. The keypad can be operated either by the user's foot or hand, depending on the mounting location.

Pedal switch cluster

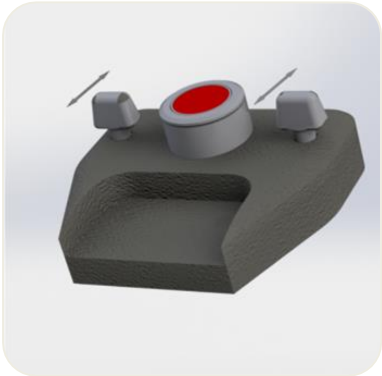

FIGURE 6.12: PEDAL SWITCH CLUSTER

(Author, 2015)

The pedal switch cluster addresses the challenges faced with regard to the emergency brake and gear-selecting operation as a gear change system similar to a tip-tronic was installed. This means that the user would simply have to tap the gear switch in an up or down direction to move the gear lever to the next or previous position. According to Participant X , this design was an improvement over the original system since she could now concentrate on driving rather than worry about selecting a desired gear position (Participant X , 2015). The emergency brake worked on a similar principle. The user could activate and de-activate the emergency break by the push of a button. The speed of the emergency brake activation was also addressed by using a faster activating actuator in the simulator.

The pedal switch cluster adheres to the following UD criteria:

- Equitable use (fair and impartial)
- Flexibility in use
- Simple and institutive use
- Perceptive information
- Tolerance for error
- Low physical effort

6.1.1 Methodology contribution:

6.1.2 Combining Universal Design with a Case Study with a Limiting User, and using a PD process within a Meta-Design team approach.

What follows is a discussion of the contribution which this research has made towards the concept of combining methodological approaches. The project was underpinned by the concept of Universal Design and was planned, executed and analysed, using a case study methodology. The case study was carried out with a limiting user, employing participatory design and involving a Meta-design team. Both UD and Case Study methodology, as well as the novel combination of the two in one project will be discussed.

6.1.3 Universal Design

The concept of Universal Design suggests that all elements and spaces be accessible and usable by all people to the greatest extent possible (Dalcher, 2006). This is carried out in all aspects of design through thoughtful planning with the focus on accessibility (Design, 1998:3). The Centre for Universal Design at the North Carolina State University assisted in the practical application of Universal Design by formulating seven principles of Universal Design (Aslaksen et al., 1997):

- Equitable use
- Flexibility in use
- Simple and institutive use
- Perceptive information
- Tolerance for error
- Low physical effort
- Size and space for ease of approach in use

See Appendix E for a full description of the UD principles and guidelines.

The research carried out in the simulator and adaptive system adheres to these seven guidelines of Universal Design and breaks new ground by embedding a case study research approach in the overall UD framework. The UD approach was the foundation on which the project and accompanying research were based. Other theories had been explored, but UD was the anchor that guided the research.

The project and this dissertation contribute to UD in the following manner. Initially I, the author, understood that research based on the concept of Universal Design needed to be conducted in a qualitative manner and would, therefore, include as many users as possible. However, the opposite was found to be true in the case of focusing on a limiting user. This study proves that a case study research approach, involving a limiting user, can contribute towards defining extreme design parameters within a Universal Design framework. Case study research, if used on its own to define design parameters, could not have resulted in a Universal Design product based on the UD criteria mentioned above. Therefore, case study methodology allowed me to define the phenomenon to be studied, as well as the approach of the study.

Case Study Research

Stake (2005:433) understands case study research as follows: 'Case study is not a methodological choice but a choice of what is to be studied'. The focus of the case study can be a person, group, institution, a country, an event - anything that the researcher wishes to study (Thomas, 2011). In this dissertation, the aim was to gather and analyse information regarding the following question: How do human factors affect the development of simulator controls for differently abled drivers? To be able to answer this question I had to understand which product and automotive factors influence the adaptation of assistive controls, which contextual factors influence the adoption of an assistive control system, and how a simulator could be developed with the focus on Universal Design criteria in order to address these challenges?

Combining Universal Design with case study research provided a framework which led to the design and construction of a product accessible to as many differently abled drivers as possible. To achieve that goal, a differently abled driver became the phenomenon which the case study observed and analysed. Although initially this approach was thought to be contradictory to Universal Design, I found that choosing a suitable person, who represented a larger community of a limiting users, contributed towards Universal Design. Pheasant introduces a limiting user as a member of the user population who, because of his or her physical characteristics, imposes the most severe constraint on the design of a product (Pheasant & Haslegrave, 2006:27). Consequently, I could choose a differently abled driver to represent a larger group of drivers and still adhere to the Universal Design criteria. Case study research contributed towards the UD approach in that it allowed for in-depth research in which the limiting user could be interviewed several times until a consistent result was obtained (Thomas, 2011).

Merging UD with a limiting user and case study research allowed me to look at the bigger picture of the research problem: How do human factors affect the development of simulator controls for differently abled drivers? The study involving Participant X could answer only certain questions that were related to her circumstances. Using case study research methods, such as observation and interviews, allowed me to gain an in-depth understanding of the research problem. Once I had gained this in-depth understanding, I could step back to view the result of the study through the lens of Universal Design. The challenge involved in this approach was the change of focus from overview to in-depth research and back to overview in a continuous cycle. This cycle is better explained in figure 6.13 below:

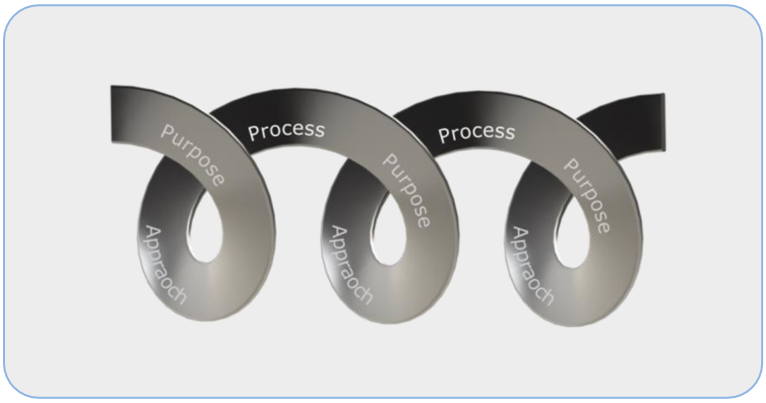

FIGURE 6.13: DISSERTATION MAP KEY

(Designed by the author according to findings by Thomas, 2011)

The dissertation map key is the overview of the research whereas the PD cycle Figure pg. 44 is the in-depth process followed. The PD cycle (plan, act/observe, analyse/plan) was repeated several times, enabling me to evaluate the limiting user's input against the UD criteria. What I learned through this combined approach is that, although differently abled users are unique in their level and type of physical abilities, they can provide the researcher with valid information because of the constraint they put on a product. In this case, qualitative research contributed to Universal Design. On the other hand, UD design allowed a differently abled driver freely to access and use a product and, at the same time, also guide the product design. However, s/he does not dictate the outcome of the study. PD allowed for triangulation within the case study research approach. Triangulation of the data collected was vital to a consistent result. Design, which involved a limiting user, meant interviewing the person on several occasions, using different scenarios and settings. This approach replaced the need for one multi-user workshop.

For this study, observation workshops were scheduled far apart; thus enough time was allowed for the limiting user to take part in a workshop without remembering exactly what had occurred during the previous workshop. The challenge in this approach was to be creative in the workshops conducted and not allow data collected at a previous observation workshop to influence the results of the current workshop.

Participatory Design supports the idea of diverse ways of planning, thinking and acting in order to consider and accommodate human needs (Schuler & Namioka, 1993). PD, as described by Gerhard Fisher (2003) and used in this research project, focuses on activities and processes taking place at the time of research, design and the construction of the simulator. As a simulator is a combination of various systems, and as the human factors influencing these systems are complex, I chose to approach various professionals who could contribute towards the overall design. This research contributed to PD by involving more individuals than just the user. Other professionals were approached as stakeholders, thus forming a design team in which every stakeholder was part of the design process - and the designer facilitated the process. This idea is not new; Fischer (2003) understands it as meta-design.

The team work in this project went a step further and proved that attitude plays an important role in the success of overcoming design challenges. Attitude can be defined as a mind-set or a tendency to act in a particular way due to both an individual's experience and temperament (Pickens, 2005). Pickens elaborates on the development of attitudes in his book 'Attitudes and Perceptions: Learning Outcomes'. He found that attitudes are formed as a result of direct experiences with people, modelling others and learning. These points complement what I, the author, observed during this study. The change of attitude occurs when one addresses the cognitive experience or knowledge and learning of the person involved (Pickens, 2005). According to Pickens, one can provide a team member with the relevant background to a new situation, as well as enough information to understand the situation, in order for him or her to make an informed choice. As the research came to an end, Pickens' view was proved to be true: the stakeholders involved had more empathy with one another when engaging in conversation. I noted that, although people from different disciplines tried to prove their point of view at the beginning of the project, there was, at the end of the project, an acceptance for different points of view and a willingness to contribute towards the goal of building a simulator based on Universal Design.

6.2 Limitations

Although this study aimed to design a UD-based simulator, choosing a case study research approach, with a limiting user, allowed for a set of adaptive controls that would suit only the limiting user. Kroemer (2006:4) supports this limitation in his findings of the unique ergonomic profile of individuals with disability; only one set of adaptive controls was designed to suit a particular individual. Therefore, to adhere to the UD nature of the project a modular approach was taken with the design of an adaptive control system so that further research can be carried out with other users and adaptive controls.

The simulator design was tailored to the availability of resources, such as workforce and funding. The funding allocated to the project was in the region of R250 000. The workforce consisted of me, two mechanical engineering students and an electrical engineering student, all of them working towards their bachelor's degree. All the practical work carried out in manufacturing prototypes was done by these students. The simulator shell was manufactured using a VW polo 2003 since the limiting user was familiar with this platform. This would ensure the least obtrusive observation during research. The software used in the simulator was City Car Driving version 1.2. Due to the limitations of the present study recommendations are made for further research.

6.3. Recommendations for future study

6.3.1. Adaptive aids used in the simulator

During the last iteration of the PD cycle an anthropometric specialist from the university, who had not been part of the study, mentioned that the steering joystick could benefit from a mechanism that would allow the driver a more natural movement when steering the simulator. As time constraints did not allow further research into this recommendation, it is suggested that future research be carried out in this regard. The specific area of study could involve an adjustable steering joystick, as well as a seat-mounted versus a door-mounted joystick.

Furthermore, a greater number of drivers with unique disabilities could benefit from a set of adaptive controls specific to their disability. The author would, therefore, recommend further study into various adaptive controls to be used in the simulator to accommodate drivers with different abilities to Participant X who took part in this study. As Participant X trained in the simulator, the author noted that during a 30 minute training session no sign of simulator sickness was evident. The author does not have a definite explanation for the absence of simulator sickness in this particular instance. Therefore, further research into the factors which may or may not induce simulator sickness in simulators in general would benefit the literature on the subject.

6.2.1 Other areas for further study

This study showed that, although the simulator was meant to be a product for driver training, various other gains were made concerning multi-disciplinary teamwork, professional capacity building and practical experience for the students involved. The author would, therefore, suggest further research into the above mentioned areas as well as ideal conditions for communication within multi-disciplinary teams, because of attitude change. I acknowledge that disciplines like Organisational Theory, Behaviour Sciences, UD and PD have actively been reviewing the impact on participants working in groups. For further study a case could be made for the comparison of in situ design experiences, as noted in this project, and various theories that relate to group experiences, learning and participation. This aspect was not in the scope of this project, but emerged as a key are of influence that deserves further investigation.

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8 APPENDIX A: CPUT CONSENT FORM

Department of Industrial Design in the Faculty of Informatics and Design at the Cape Peninsula University of Technology

*"Consent form FOR RESEARCH PARTICIPANTS adapted from a template (available at: www.ucc.ie/**research**/rio/documents/In**formed**ed**ConsentForm**Template.doc)"*

The aim of this form is to facilitate informed consent by communicating with participants in a language that they can understand.

Purpose of the study: As part of the requirements for a Master of Technology degree at Cape Peninsula University of Technology, I have to carry out a research study. The study is concerned with Universal Design in Automobiles focusing on steer-by-wire controls. The study will involve informal, as well as formal interviews, user testing of prototypes, as well as and not limited to ergonomic and anthropometric data capturing of participants.

- Participation is voluntary.
- Anonymity will be respected where requested.
- Any research data will be kept and published on completion of the thesis unless otherwise requested.
- What will happen to the results?

  The results will be presented in this thesis.
- What are the possible disadvantages of taking part?

I do not envisage any negative consequences of your taking part. It is possible that speaking about your experience in interviews may cause some distress.

- Any further queries?

  If you need any further information, you are welcome to contact me or my supervisors:
- Gerhardus Coetzee
  - Tel. +27744806256
  - E-mail: coetzee.gerhard1@gmail.com
- Supervisor: Vikki Du Preez
  - Tel: +27 21 460 3820
  - E-mail: DuPreezV@cput.ac.za
- Co-Supervisor: Prof. Mugendi M'Rithaa
  - Tel: +27-21-4691027

  1.1.1. E-mail: MugendiM@cput.ac.za

- Co-Supervisor: Prof. Oscar Philander
    - Tel: +27-21-953 8535
    - E-mail: PhilanderO@cput.ac.za

If you agree to take part in the study, please sign the consent form overleaf.

9 APPENDIX B: CPUT CONSENT FORM

I……………………………………agree to participate in [*Gerhardus Johannes Coetzee*]'s research study.

The purpose and nature of the study has been explained to me.

I am participating voluntarily.

I give permission for my interviews with [*Gerhardus Johannes Coetzee*]] to be recorded in

☐ Audio

☐ Visual

I understand that I can withdraw from the study, without repercussions, at any time, whether before it starts or while I am participating.

I understand that I can withdraw permission for the data to be used within two weeks of the interview, in which case the material will be deleted.

I understand that anonymity will be ensured in the write-up by disguising my identity if I so wish.

I understand that extracts from my interview may be quoted in the thesis and any subsequent publications if I give the required permission below:

(Please tick one box:)

☐ I agree to quotation/publication of extracts from my interview

☐ I do not agree to quotation/publication of extracts from my interview

Signed……………………………………. Date……………….

10 APPENDIX C: TABLES

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
	Manual	Photo	Manual	Photo	Manual	Photo	Manual	Photo	Manual	Photo	Manual	Photo
Stature	115.2	115.6	115.4	114.9	115	115.6	114.9	115.5	115	115.5	114.6	115.5
Shoulder height	84.2	86.9	84.5	85.8	84	86.2	84.9	87.3	84.6	86.9	84.3	87.1
Trochanteric height	40.9	42.1	43.2	44.0	43.7	45.0	45.3	46.7	42.4	43.2	43.3	45.6
Knee Height	24.6	25.2	25.1	25.0	24.4	25.2	24.8	25.6	25.3	25.9	25.7	25.9
Ankle Height	5.2	4.7	5.3	4.6	5.5	5.3	5.4	5.2	5.4	5.2	5.4	5.6
Foot Length	17.8	19.0	18.6	18.7	18.4	18.5	18.8	18.7	18.8	18.8	18.6	18.8
Upper Arm Length	16.8	18.6	18.7	18.7	18.6	18.9	18.2	18.9	18.4	18.8	18.2	18.5
Forearm Length	14.9	15.0	15.9	14.5	15	14.5	14.1	14.8	14	14.3	14.9	14.8
Hand Length	12.9	12.4	12.4	12.3	12.6	12.5	12.7	12.4	12.8	12.7	13	12.6
Hand Breadth	6.3	6.9	6.7	6.8	6.5	6.9	6.5	6.7	6.6	6.7	6.6	6.4

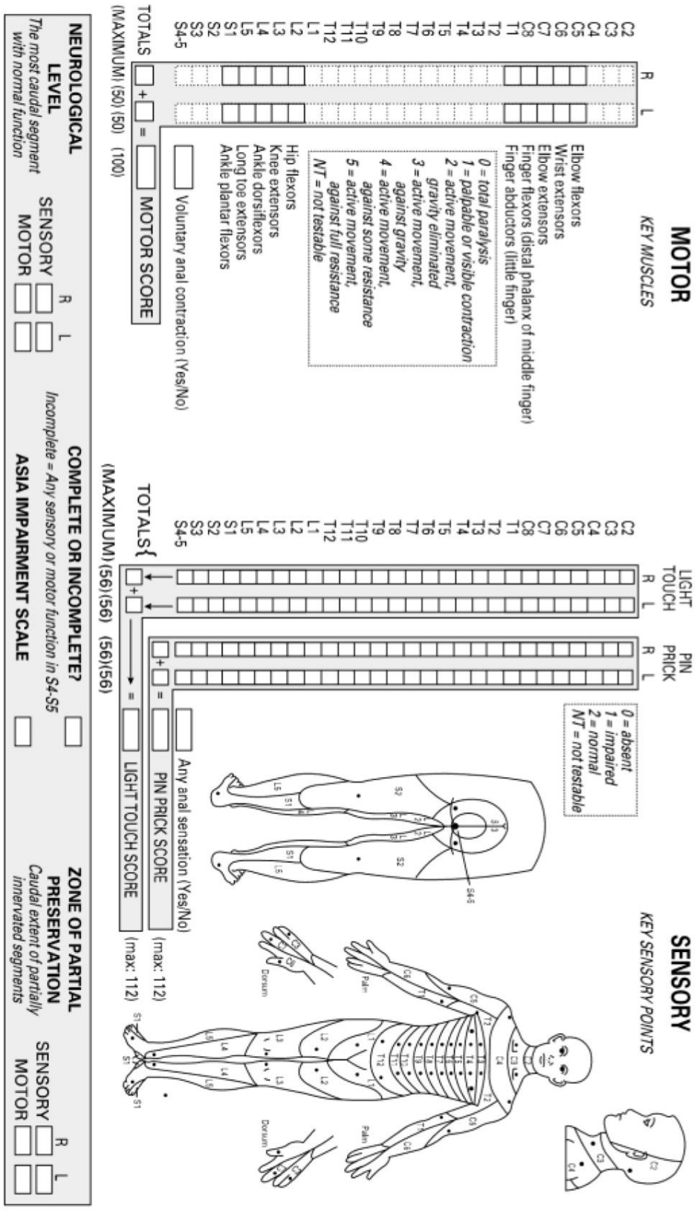
Table of basic static measurements for people with Achondroplasia type dwarfism.

(Ferguson. 2007)

	Mean (cm)	Standard Deviation (cm)	Coefficient of Variation (%)
Stature	121.46	12.63	10.40
Trochanteric Height	52.35	8.34	15.94
Ankle Height	6.01	1.42	23.61
Upper Arm Length	20.56	4.16	20.24
Forearm Length	16.18	3.52	21.77
Hand Length	12.85	2.21	17.22
Hand Breadth	7.38	0.83	11.28
Foot Length	18.80	3.29	17.52
Shoulder Height	94.07	11.72	12.45
Elbow Height	74.17	9.32	12.57
Wrist Height	61.71	7.69	12.47
Fingertip Height	50.16	5.88	11.72
Knee Height	29.90	4.40	14.70
Biacromial Breadth	33.59	3.98	11.85
Hip Breadth	34.21	4.10	11.99
Foot Breadth	8.77	1.05	11.99
Sitting Height	77.97	7.84	10.05
Sitting Shoulder Height	50.09	5.76	11.49
Elbow Rest Height	29.08	5.75	19.76
Buttock to Popliteal Length	29.85	4.36	14.61
Popliteal Height	21.41	4.00	18.68
Buttock Breadth Sitting	37.81	4.26	11.26

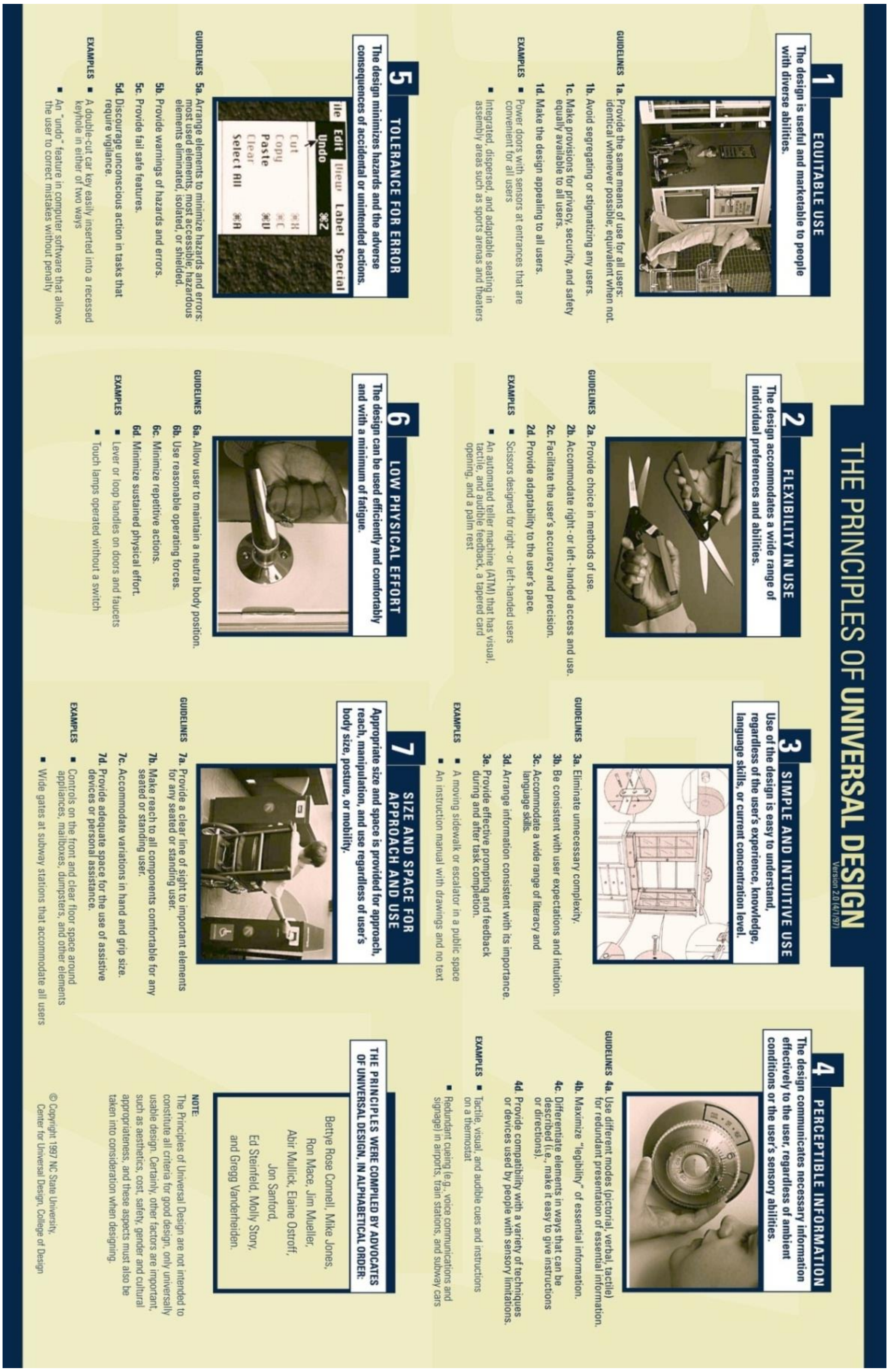
Summary of static measurements for people with persons with Achondroplasia type dwarfism. (Ferguson. 2007)

11 APPENDIX D: SPINAL CORD CHART



The above diagram is the Standard Neurological Classification of Spinal Cord Injury. Reproduced from International Standards for Neurological Classification of Spinal Cord Injury, revised in 2000. American Spinal Injury Association/International Medical Society of Paraplegia (Grundy & Swain, 2002).

12 APPENDIX E: UD GUIDELINES



13 APPENDIX F

13.1 Attached Compact Disc with Raw Data

This Figure Illustrates the folder layout on the attached DVD of all data collected during the field research process