UNIVERSITY OF NAIROBI

SCHOOL OF ARTS AND DESIGN

CENTERING THE MAKER IN MAKERSPACES; AN EXPLORATORY STUDY OF THE UNIVERSITY OF NAIROBI'S MAKERSPACE

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B51/11850/2018

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May 26, 2020

DECLARATION

STUDENT:

I, Undersigned, declare that this is my original work and has not been submitted to any other institution, other than the University of Nairobi, School of the Arts and Design.

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DEDICATION

To my parents, problem-solvers out there and 3D printing Enthusiasts in Africa. African problems will be solved by Africans; keep pushing the scholarly boundaries and believe in you.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Makerspaces are creation spaces, equipped with digital fabrication tools and equipment for use by makers. Access to these expensive tools and networks has made makerspaces popular globally. Internationally, universities have acknowledged the significance of makerspaces in academic spaces and introduced them to the university community. The University of Nairobi hosts the UoN makerspace, located at the College of Agriculture and Veterinary Sciences, Upper Kabete campus. The makerspace is meant to give students access to fabrication tools to enhance learning through a hands-on approach and inspire multidisciplinary collaboration. Despite the rapid growth of makerspaces as open spaces for creativity, innovation, and experiential learning, the role makers play in makerspaces remains unknown. While the need for makerspaces in academia has been well studied, there is limited knowledge of the makers who use the makerspaces. To remedy this gap, the researcher conducted an exploratory study on the makers and their experience in makerspaces. The researcher provides a detailed context and knowledge on Makerspaces, makers, methods, tools, and spaces using a case study of the UoN Makerspace, triangulated with secondary data from other academic makerspaces. The literature review explores the Maker Movement; its history, benefits, and opportunities. The influence of Makerspaces in areas of higher learning is also explored in depth. This qualitative study used exploratory research and participatory design through a process of co-design. Data were collected through observation, key informant interviews, a focused group discussion with UoN Makerspace makers and co-design through an HCD Design Sprint to redesign the "Retr3D Printer". The contribution of this research is both empirical and theoretical. Empirically, the researcher provided an in-depth review of academic makerspaces, maps the makers and engagement process in makerspaces, looked at the making process in makerspaces using Human Centred Design (HCD) then proposes an appropriate model for centring makers in academic makerspaces. The maker was found to be the most important “component” of any makerspace,

with the students being the majority makers in the UoN makerspace and other higher education makerspaces in general. It was established that although makers are core to the makerspace, very little attention is given to them. Although collaboration and creativity are key in makerspaces, the UoN Makerspace was engineering-focused with very little collaboration with other members of other disciplines. The research noted a gap in awareness; members from other faculties were not aware of the UoN Makerspace let alone how they could use the facility. The making process was also a challenge to new makers accessing the facility for the first time. The typical making process was too technical (engineering design process), making it hard for non-technical users use of it. There were also concerns about the alternative design thinking processes being time-consuming. The researcher proposed an "HCD Design Sprint" that was quicker and incorporated multidisciplinary teams and used it to create a 3D printer in 4 days. Theoretically, this research paves the way for an in-depth understanding of makers and their experience in Makerspaces.

LIST OF ABBREVIATIONS AND ACRONYMS

CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CAVS	College of Agriculture and Veterinary Studies
CNC	Computer Numerical Control
DIY	Do-It-Yourself
FDG	Focused Group Discussion
HCD	Human Centred Design
MNCH	Maternal and New-born Child Healthcare
PPH	Postpartum Hemorrhage
UoN	University of Nairobi

1 CHAPTER ONE
INTRODUCTION TO THE STUDY

1.1 Introduction

This chapter provides the background to the research, the statement of the problem, the objectives of the research and the related research questions. The justification for the research, scope, and limitations of the research are also provided in this chapter.

1.2 Background: Makerspaces

A makerspace, according to Farritor, (2017) is a "physical space where individuals can build and create." Makerspaces are prototyping spaces where users utilise traditional and digital technologies to explore ideas, learn technical skills, to create new products (Sheridan *et al*., 2014). Simply, it is a one-stop centre where innovators, creatives, mentors, and learners have access to tools and equipment, for the execution of projects. Collectively, makerspaces are open spaces for creativity, innovation and experiential learning where makers have access to manufacturing tools and machines to build physical prototypes (Weinmann, 2014).

Globally, makerspaces are gaining traction (Farritor, 2017), for rapid prototyping and innovative thinking (Artut, 2018). Over the last decade, over 1400 makerspaces were established, up from about 100 in 2006 (Lou & Peek, 2016), with 150 being on university campuses (Wilczynski, *et al.,* 2017). This number is however conservative, with new makerspaces coming up every year. Despite this phenomenal growth, makerspaces are still elitist, with the most people in academia unaware of makerspaces; who the makers are and how they could incorporate them in their disciplines. While there is a push to establish makerspaces in academia, there is limited literature on the most important component in the makerspaces; the makers.

1.3 Kenya’s Makerspace Landscape

There are seven makerspaces in the country; four in Nairobi, one in Kisumu, and three in or around Mombasa (Baarbé & Nzomo, 2017). The most notable local maker centres include the Gearbox, Fablab Nairobi, Fablab Kivuli, Fablab Winam and the UoN Makerspace. All these makerspaces are located in universities, manufacturing parks, community centres, or incubation hubs.

Makerspaces in Kenya operate on different governance models; some are NGO-funded, others operate as university departments or as for-profit makerspaces. NGO-funded and university makerspaces are free for makers while for-profit makerspaces like Gearbox, require members to pay a membership fee to use the services.

1.4 Problem Statement

Makerspaces are becoming popular in universities as a new approach to enhancing creativity, innovation, allowing for creation, prototyping and hands-on learning. Despite the rapid growth of makerspaces as open spaces for creativity, innovation and experiential learning, the role makers play in makerspaces remains unknown. While the need for makerspaces in academia has been well studied, there is limited knowledge of the makers who use the makerspaces. Whereas the role of makerspaces in and experiential learning has been researched extensively, there is little on the makers in makerspaces; who they are and what they do. The literature review has shown that there exists a huge gap on who the makers are and their role in a makerspace, yet makers are the most important component of any makerspace. Having identified this gap, the researcher carried out exploratory research on makers in makerspaces using the University of Nairobi’s (UoN) Makerspace as a case study.

1.5 Research Objectives

The main objective of this study is to build and gain an understanding of university makerspaces and the role makers play in those spaces. The research objectives for this study can be summarized as:

1. To map out the makers and the engagement process in academic makerspaces.
2. To articulate the making process at the UoN makerspace using a human-centred design approach.
3. To propose an appropriate engagement model for makers in academic makerspaces.

1.6 Research Questions

1. Who is a maker and how do they engage within an academic makerspace?
2. What is the typical making process at the UoN makerspace?
3. What engagement model would be appropriate for makers in academic makerspaces?

1.7 Scope and Limitations

The study confined itself to a thematic scope aimed at identifying key makers in the use of Makerspaces in Kenya. The project was also limited to a case study of the UoN Makerspace located at the College of Agriculture and Veterinary Sciences (CAVS), Upper Kabete Campus. Triangulation was done using secondary data on academic makerspaces globally.

1.8 Need for Study

The maker movement and our understanding of making in makerspaces are still at their infancy (Honey & Kanter, 2013). Even though the art of making and hands-on making has been practised for centuries (Wong & Partridge, 2016), makerspaces as prototyping hubs for innovation and creativity are a recent phenomenon (Otieno, 2017) and there exists limited research on the makers and their contribution in makerspaces, despite being the most important component in the maker movement.

Makerspaces as prototyping spaces allow users to get hands-on experience, make artefacts, collaborate and iterate. They offer a conducive environment to tinker, innovate, create and build solutions (Farritor, 2017; Weinmann, 2014). The need for makerspaces has been extensively studied in academia, (Blikstein, 2013; Burke, 2015; Institute of Museums and Library Services, 2014; Michelle *et al*., 2013; Wilczynski *et al*., 2017) with the potential benefits across different disciplines highlighted. But questions still arise on the "people" who use the spaces and how they use them. These questions have not been answered by previous research. Through this study, I intend to inform this gap in research to centre the makers in makerspaces by exploring the methods, tools and spaces in academic makerspaces in relation with their users.

1.9 Significance and Implications

The goal of the study was to understand the makers and their experience in university makerspaces. This research further intended to determine how university makerspaces function; the methods and tools used in makerspaces in the making process. The knowledge gained from the study has implications for the maker movement, makerspace users, policymakers, students and universities that intend to start and operate makerspaces.

1.10 Conclusion

University makerspaces around the world, are on a rapid increase. They are offering a platform for innovators, students and creatives to gather, collaborate, share and build. The availability of resources that otherwise could be too expensive for an individual to acquire, make makerspaces very attractive. Despite their popularity, makerspaces are still elitist with very little known on the makers. While the need for makerspaces in academia has been well studied, there is limited knowledge of the makers who use the makerspaces. To bridge this gap, the researcher carried out exploratory research on makers in makerspaces using the University of Nairobi's Makerspace.

The research is a case study of the UoN Makerspace, the makers and the engagement process in academic makerspaces was mapped out. The researcher then tested how HCD can be used to enhance the making process at the UoN makerspace through an HCD Design Sprint. Finally, resulting in the development of an approach that can be used to centre makers in academic makerspaces.

2 CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

This chapter provides an overview of the background necessary to understand this study. Because of the nature of this study, a thorough review of the literature was conducted to understand makers and makerspaces.

2.2 Maker Movement

The maker movement broadly refers to the people who are engaged in the creation, building and making of physical and tangible solution (Halverson & Sheridan, 2014). It advocates for the notion that everybody is a maker rather than being just a consumer (Otieno, 2017). The origins of the movement are rooted in need to create actual objects. (Dougherty, 2012). Makers in the movement are engaged in the creation and assembly of products employing traditional technologies like crafts, sewing and woodwork to use of new technologies like 3D printing and laser cutting (Rosa, *et al.*, 2018).

The popularity of the movement can be directly linked to the *Maker Faire* by Dale Dougherty's *Make* magazine (maker Media), founded in 2005. "The *Maker Faire* events allowed makers to interact with one another, leading to a level of interconnectedness that has helped build a movement" (Dougherty, 2012). The maker faires together with internet-enabled people to share, and collaborate. Connected by passions and enthusiasm, makers from multiple disciplines; arts, science, engineering and crafts continue collaborating with a common aim of creating and building solutions. The Maker media, gave the movement the much-needed publicity giving it a boost. It offered an avenue for hobbyists, start-ups and enthusiasts to showcase and share their creations leading to collective aspects of making (Lui, 2016).

Today, the maker movement has grown from its remote origins as a movement of hobbyists, tinkerer and enthusiasts (Vossoughi, *et al.,*2016) into education, business and even government. Institutions see the movement as an opportunity to innovate and solve problems in a controlled environment (Dougherty, 2012). Education was the first industry to see the potential of the movement, with Fablabs (Stacey, 2014), K-12 makerspaces (B. Taylor, 2016), libraries (Curry, 2017) and academia (Farritor, 2017) quickly adopting it for hands-on and experiential learning.

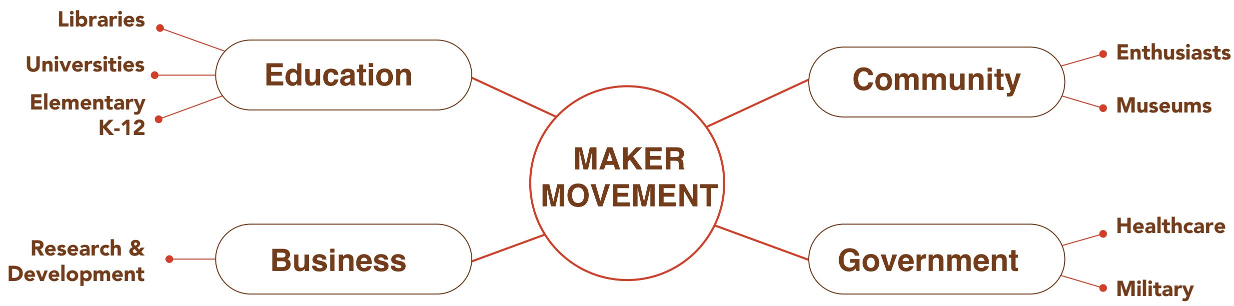

Figure 1: Maker Movement (Source: Author)

Although the movement does not have official guidelines, there has been an attempt to provide "Rules of Innovation" by Hatch, (2013). In "*The Maker Manifesto*", Hatch describes guidelines to the maker movement; Make, Share, Give, Learn, Tool Up, Play, Participate, Support and change (2013, pp. 1–2). The maker movement pegs its origins to the culture of making physical things, that can be shared with others in online communities. The act of giving and learning from others (new techniques, material and processes), to make and the ability to access tools "open hardware" is what the maker movement is all about (C. Anderson, 2012). To enhance creativity, the manifesto advocates for play, using the resultant excitement to discover and create. Generally, the maker movement operates under the DIY (Do-It-Yourself) approach, applying new technologies like 3D printing and laser cutting, with collaboration and access to information as the *modus operandi.*

The movement has democratised the access to tools and skills that previously were only accessible to specialists in research labs (Sheridan *et al.*, 2014). This compounded with the availability of resources (low-cost hardware, access to digital fabrication tools, and shared projects) has seen an increasing number of educators and researchers identifying with the movement (Vossoughi *et al.,* 2016). Essentially, the movement has led to the rise of *open-source* creation, inspiring creation and sharing of assets to the whole community (Rosa *et al.*, 2018).

Initially, a preserve of STEM fields (Wilczynski, 2015), there is a push to have makerspaces in the creative spaces; Arts, Design, Architecture, for innovation (Park *et al.,* 2018). As a magnate for sharing, participation and collaboration, the maker movement continues to attract people from different disciplines enhancing multidisciplinary environments (Martin, 2015). The movement has led to a philosophy of sharing, acceptance and creativity that can be replicated across multiple disciplines, in line with the belief that "everyone is a maker" and that we are architects of our world.

Halverson & Sheridan (2014) assert that the movement has three components key components; making (methods and processes of creation), makerspaces (the spaces where the making happens) and makers (the people involved in the making). Whereas the first two components have been studied widely in literature, there is very little on the human perspective of the movement. The three components are further elaborated in subsequent sections of this review.

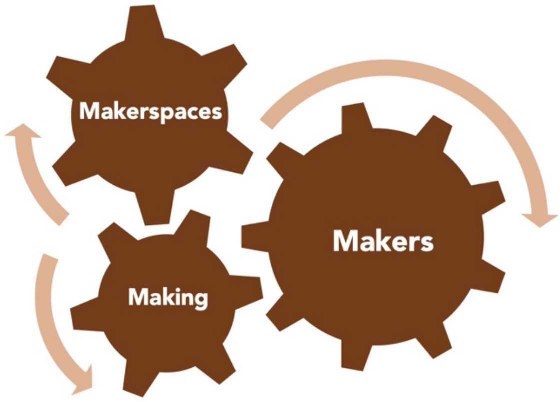

Figure 2: Components of the Maker Movement (Source: Adapted from Bassolino, 2019)

2.2.1 Maker Movement; Opportunities and Challenges

The maker movement, for the two decades, that it has been around continues to show great potential, allowing artisans, tinkerers, inventors and students to move product development in makerspaces to mass production without requiring prior infrastructure (Dougherty, 2012). It has made producing cheaper, allowing for creation without factories (Blikstein, 2013; Doussard, *et al.*, 2018). The movement has even been touted as the precursor to the next industrial revolution as a result of associated technologies like 3D printing (C. Anderson, 2012; Hatch, 2013). With additive manufacturing; which is the cornerstone of the maker movement, growing rapidly, scholars have predicted that the 4^{th} Industrial revolution has just started (Monahan *et al.*, 2015).

As a result of collaboration and sharing, the potential of makerspaces for peer-learning was quickly noticed by centres of higher education like MIT, Georgia Tech, Yale among others as centres of alternative learning. Availability of makers with different degrees of know-how, working alongside relatively new members, led to the training of the new members on how to design and create products. Members could also experiment with new techniques and tools from observing other makers using different mediums to create similar products quicker and more effectively (Burke, 2014). This has seen universities adopt makerspaces as a tool of learning and training.

In education, STEM fields have already embraced the movement with K12, and higher education institutions embedding makerspaces in their curriculums (Johnson, 2018; Marsh *et al.,* 2017; Wilczynski, 2014; Wong & Partridge, 2016). Makerspaces allow for a hands-on approach to education, enhancing experiential learning incorporating play and experimentation in education. Makerspaces have actualised constructivism and constructionism through project-based learning.

The maker movement has so far democratised invention and innovation through access to resources that were previously restricted to access to industry Research and Development departments (Browder, *et al.,* 2019). Now makers have access to information and knowledge through collaboration resulting in innovative solutions.

Through rapid prototyping and digital fabrication, creation of solutions is now faster than ever before (Balogun *et al.,*2018). The product development process from idea to market period has been reduced incredibly as a result of new processes and access to new tools.

The maker movement has, however, come under intense criticism on the composition of the makers, in the makerspaces. The critics point out that only 15-19% of the makers are female (Bean *et al.,*, 2015; Williams, 2018), showing the gender inequality in the maker movement. Faulkner & McClard (2014) found out that this is due to the type of making that women do in makerspaces (nontechnical) and that women tend to shun makerspaces because they tend to be masculine.

There is also a lack of documentation of who the actual makers are. The available literature barely recording who the users are and how they use the space. This makes it difficult for their adoption in Academia.

2.2.2 Hackerspaces

Hackerspaces, as the name suggests, are directly linked to hackers involved in problem-solving as well as the creation of novel solutions. These are spaces where hackers can express themselves independently with access to information; embracing hands-on creation and peer-to-peer learning processes while sharing their creations with other hackers (Niaros, 2016, pp. 12, 13).

Hackerspaces are non-repressive spaces where programmers and tinkerers meet, work and learn from one another (Rosa *et al.,*2017). Hackerspaces are community-run and member-driven spaces, relying on membership fees to operate (Karre, 2015), hackers meet and work on their projects, while learning from one another (Hira & Hynes, 2018).

Inspired by opensource software, hackerspaces first appeared in the late 80s and early 90s as places for tech enthusiasts to meet, invent and repurpose devices (Blikstein, 2018). Starting in August 1995 in Berlin Germany, the C-Base is considered the first hackerspace to be founded. In reaction to the overly protective model by electronic manufacturers, hardware engineers wanted a scenario where tech would be opensource. This inspired the maker movement. The initial community hackerspaces in the USA are attributed to the Chaos Communication Camp (an international hackers meeting) who went on to start their own spaces; like the *NYC Resister* and *Noisebridge* (Lui, 2016). These gave precedence to future establishments that became makerspaces.

2.2.3 Fablabs

Fablabs (Fabrication Laboratories) is a network of spaces that are dedicated to the building of items, providing digital equipment for designing and creating physical products (Gershenfeld, 2005). Fablabs are designed for low-cost rapid prototyping and digital fabrication (Blikstein, 2013) to promote collaboration and sharing ideas among member labs. The Fablab model has created a global network of local labs for innovation, providing access to tools for digital fabrication to individual makers.

According to the "*The Fab Charter",* the mission of Fab labs is to create a worldwide network of home-grown labs, for innovation by proving access to tools for digital fabrication (United States Fab Lab Network, 2011). They also seek to provide training to individuals based on doing projects and learning from peers. Finally, the fab charter seeks to promote responsibility among makers through; *(1) Safety;* Cleaning up, operations and maintenance, *(2) Secrecy*; designs and process developed in Fablabs can be protected through intellectual property & patents, and *(3) Business*; allows for the incubation of businesses in form of start-ups (2011, p. 21).

Started at the MIT Media Lab by Prof. Neil Gershenfeld, Fablabs have a list of equipment and guidelines required to join the network. Working from a hands-on, interactive and do-it-yourself notion, a Fablab must have laser-cutters for 2D & 3D structures, sign cutters for circuits, milling machines for precision parts, a CNC ShopBot for 3D cutting and carving wood or plastic, programming tools for microcontrollers and a 3D printer (United States Fab Lab Network, 2011).

The Fablabs are generally set-up within institutions like universities, companies or foundations(Rosa *et al.,* 2018). With at least 1500 Fablabs worldwide (FabLab Lo, 2018), the Fab Lab model has been replicated across the world with institutions operating under a common mission. The Fab Lab Nairobi, domiciled at the University of Nairobi's Mechanical engineering Department offers a space for creators and is run in line with Fab Lab mission; innovate, educate and collaborate. The Fab Foundation continues to support the creation of new Fablabs worldwide, in the training and development of local networks.

2.2.4 Makerspaces

Makerspaces, also known as Creative Spaces, Fablabs or Makelabs, are places where individuals can build and create (Farritor, 2017; Weinmann, 2014). They serve as centres for learning, collaboration, problem-solving, self-expression and rapid prototyping (Kemp, 2013). Wong & Partridge, (2016) defines them as "a physical site where people gather to share resources, work on projects, network and build items." These are Do-It-Yourself centres where makers create using technology while working alongside one another (Otieno, 2017).

They are common spaces where participants create practical projects to reinforce their knowledge and skills based on their internal motivations (Artut, 2018). Makerspaces, unlike school labs, attract people who are not compelled to use them. Through intrinsic motivation makers voluntarily access the fabrication space to build solutions, not receiving academic credits.

Marsh *et al*., (2017) in their definition focus on the components of makerspaces, defining them as spaces that enable makers to create solutions using professional tools and resources. Morocz (2016) and Taylor *et al*., (2016) contend that the attractiveness of the spaces lie on the availability of resources and tools that are otherwise too expensive for makers to afford but can be accessed at makerspaces. This study will employ the general definition by Bergner & Chen, (2018) for this thesis. "*Makerspaces are physical spaces where making enthusiasts of all ages and levels convene to ideate, design, prototype, produce, test, hack, and improve tangible products"* (Bergner & Chen, 2018, pp. 551–552).

Although Makerspaces originated from hackerspaces (Burke, 2015), the launch of *Make: Magazine* in 2005, by Dale Dougherty, is considered the catalyst of the current maker craze (Burke, 2014). Dougherty initiated *Maker Faire* for makers to share their creations, giving traction to the idea of makerspaces, thus democratized the process of making. Maker Faire(s) resulted in pushing the idea of coworking and collaboration among enthusiasts leading to a multi-dimensional approach to creation. This changed the process of making from an isolated activity to a group effort in a shared space. The idea of people from different disciplines working collaboratively was born and encouraged in the new maker movement.

Makerspaces in academia, are however attributed to the creation of Fablabs, by Prof. Neil Gershenfeld of MIT's Centre for Bits and Atoms to enable people across the globe to become make use of technology rather than being tech outsiders (Burke, 2014; Kohtala & Bosqué, 2014).

In academia, makerspaces took the form of university makerspaces, K-12 makerspaces and library spaces. They fused hands-on approaches and creativity to enable students to research, build and create solutions both personal and group projects (Sheffield *et al.,*2017). The initial adoption was in STEM but quickly moved into Arts and other creative spaces. Makerspaces in different spaces are discussed further in the subsequent section.

2.2.5 Kinds of Makerspaces

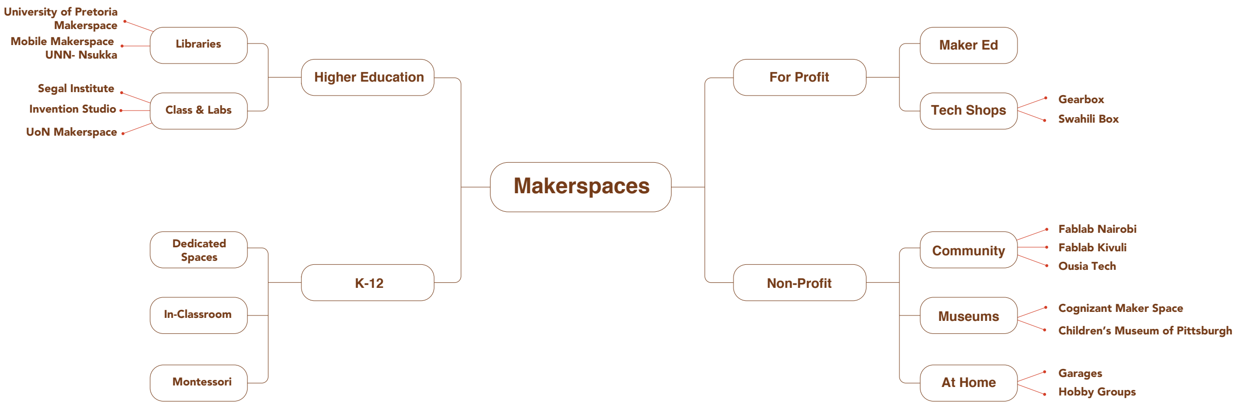

Figure 3: Kinds of Makerspaces (Source: Adapted from Bassolino, 2019)

Making happens everywhere, from the kitchen or to a well-equipped makerspace, in the village or the city, a school or a dedicated university space (Michelle *et al*., 2013). The decision on where to place makerspaces is usually determined with several factors; the size of the makerspace, the number and type of makers, funding, availability of space and the types and quantity of tools and equipment you need. The following makerspaces are classified using their location and users. However, all types of makerspaces have one characteristic in common, the deliberate need for their members to create, build or solve problems (Weinmann, 2014).

2.2.5.1.1 Community Makerspaces

Community makerspaces are fabrication spaces that are open to the public, at a fee or for free, for fabrication purposes. They are community-operated places where people can utilize digital fabrication technologies (Niaros, 2016). Peppler *et al.,* (2016) emphasise that community makerspaces offer opportunities to the common people to access tools that could be too expensive for them to purchase. Community makerspaces play several roles in their community. They offer people an opportunity to create home-grown solutions to local problems (Gershenfeld, 2005), act as social spaces – third places (N. Taylor *et al*., 2016), serving local needs for wellbeing and empowerment as well as widening access to fabrication tools. Examples of community makerspaces include; *MAKLab Glasgow*, *Dundee Makerspace*, *Westhill Men's Shed*, *MIT-Fablab Norway* and t*hemakerspace (16urban), BinarySpace (Vaal)* in South Africa and the *Gearbox* (Nairobi) in Kenya.

2.2.5.1.2 K-12 Makerspaces (Elementary Makerspaces)

K-12 makerspaces are makerspaces that are embedded in elementary schools for learning (Marsh *et al*., 2017; Ortega, 2017). They are spaces that are meant to support early childhood education through making and play with an emphasis on sharing. K-12 makerspaces help children develop their social and emotional capacities and enhance creativity. *The Edgerton Center K-12 Outreach Program* at MIT, one of the most notable K-12 makerspaces provides access to tools, activities and collaborators to children for collaborative, playful, experiential learning. K-12 educators use makerspaces to engage learners in an innovative, problem-solving through design, prototyping, and iteration (Peterson & Scharber, 2018). K-12 makerspaces expose children to high-level technology, inculcate the sense of community enabling them to develop creativity and innovation at an early age (United States Fab Lab Network, 2011). Through interactive play at makerspaces, kids engage and interact with tools, computers and machines developing cognitively, enabling imagination, dexterity, emotional and physical strength (Ginsburg, 2007).

In his study *"Evaluating the Benefit of the Maker Movement in K-12 STEM Education"* to find out the benefits of makerspaces in K-12 education, B. Taylor, (2016), concluded that the makerspace model is a progressive model for education that if implemented correctly can enhance early childhood education.

2.2.5.1.3 Library Makerspaces

Burke, (2014) defines library makerspaces as spaces that "spur learning, invention, creativity and innovation by providing space and the means of making in libraries". With books increasingly becoming available in digital format, libraries are left with space, that is both an opportunity and a challenge. This has forced them to adapt their spaces to accommodate uses like collaboration, conference rooms and computer spaces. They are becoming centres of information creation as opposed to being just information providers. The library's role in knowledge creation and STEAM education makes them perfect platforms for makerspaces (Okpala, 2016). Different scholars have researched library makerspaces, noting that for libraries to survive the 21st century they have to adapt, and view makerspaces has a viable solution (Anderson, 2017; Curry, 2017; Wong & Partridge, 2016).

Notable Library makerspaces in Africa include; *the University of Pretoria Makerspace*, *The Zenith Library Makerspace* at the University of West Africa, and the *"Mobile Makerspace"* at University of Nigeria, Nsukka. Globally, the *Chicago Public Library* and the *Odom Makerspace Library* at Valdosta State University stand out. The researcher noted that there were no library makerspaces in Kenya.

2.2.5.1.4 Museum Makerspaces

Museum-based makerspaces are "spaces that serve to cultivate a tinkering approach to problem-solving in visitors and serve to spark further interest in new audiences" (Oates, 2015). They are meant to turn visitors in museums from mere viewers to participants. Through Makerspaces, museums have leveraged on their visitors' interest in science and art, offering them an opportunity to create and build "their creations" in the museums (Halverson & Sheridan, 2014). The New York Hall of Science's Cognizant Maker Space, Oregon Museum of Science and Industry and Children's Museum of Pittsburgh through funding from the Institute of Museum and Library Services are leveraging on makerspaces to strengthen community-based learning, for critical thinking, problem-solving, collaboration, and engagement in STEAM (Institute of Museums and Library Services, 2014).

2.2.5.1.5 University Makerspaces

University makerspaces are open spaces that are embedded in institutions of higher learning (Farritor, 2017). Institutions of higher learning have incorporated makerspaces in their campuses to support institutional goals and accreditation requirements (Wilczynski et al., 2017). Universities see makerspaces as an opportunity for students from diverse disciplines together to encourage multidisciplinary collaboration, innovation, problem-solving and Entrepreneurship (Hynes & Hynes, 2018). Through multidisciplinary collaboration, students gain fresh perspectives from their colleagues, leading to innovative solutions within the University community.

University makerspaces are set up to encourage creativity and innovation, multidisciplinary collaboration, experiential learning, and even entrepreneurship (Farritor, 2017; Hynes & Hynes, 2018). They are a shared resource that is open to all university students, to facilitate interdisciplinary teams and approaches to creation (Wilczynski et al., 2017). Though they function to some extent like labs, they differ in that they are not dedicated to a single discipline or course-specific allowing for both extracurricular and personal activities.

Top university makerspaces include; Massachusetts Institute of Technology's network of small makerspaces; Stanford University's *Product Realization Lab* and the *d.school*; Georgia Institute of Technology's *Invention Studio*, Northwestern University's *Segal Design Institute*; Rice University's *Oshman Engineering Design Kitchen*; and Yale University's *Center for Engineering Innovation and Design* (Wilczynski, 2015). In Africa the University of Nairobi's *UoN Makerspace*; University of Witwatersrand's *Tsimologong* and Stellenbosch University's *LaunchLab*; (de Beer, *et al.*, 2017), standout.

The relevance of Makerspaces in Higher education

The role played by makerspaces in education has been widely studied by several scholars. Although the bulk of research has been in elementary (k-12) and high school makerspaces (Kurti, *et al.,*, 2014; Marsh *et a*l., 2017), the benefits cut across the sector.

Makerspaces bring hands-on learning into the curriculum, supporting project-based education. Hands-on learning according to recent research by Stanford University and TUM found out that it leads to multi-sensory learning fostering attention and enhancing concentration, reducing demotivation and creating positive emotions. It was also established that through social interaction and allowing students to work on their interests and ideas helps integrate academic content into real-life contexts (Weinmann, 2014). Makerspaces have enabled universities to move from teacher-centred lectures to project-based education and hands-on learning.

University makerspaces, provide tools, equipment and space for students and faculty to create. Most of the equipment in makerspaces are quite expensive to acquire as an individual but are accessible to the university community for prototyping and even the creation of finished products. Through that makerspaces in academia spur practical and artistic creations that can provide economic, educational and social rewards (Artut, 2018, p. 52).

Makerspaces are also enabling multidisciplinary collaboration among students from different disciplines. The movement operates under the dictums of sharing and collaboration, with individuals working on different projects working alongside one another. Farritor opines that "Having many people living close allows for tight collaboration and for ideas to be shared and spread. It allows for ideas to build upon other ideas and for ideas to advance" (Farritor, 2017, p. 393). This form of collaboration is the very essence upon which makerspaces are built.

Makerspaces also act as third places(N. Taylor *et al*., 2016, pp. 23, 24). These are alternative spaces separate from the home and workplace for socialisation and creative regeneration. In Universities, makerspaces offer an avenue for students away from the "classroom" to socialise and work of self-projects with "less seriousness" that would be expected in a classroom or laboratory setting.

Weinmann, (2014)*,* In his study "*Makerspaces in University Community"* summarises the benefits of makerspaces to the higher education as a) Improved engineering education, b) Increased student motivation, c) Creation of communities and networks d) New inventions and innovations, and e) Support of entrepreneurship and technology transfer (2014, p. 23). These are some of the key reasons why makerspaces are vital in higher education settings.

2.2.6 Makerspaces in Kenya

Makerspaces in Kenya can be directly attributed to Dr Kamau Gachigi, who started and led the first Makerspace in Kenya, Fablab Nairobi (University of Nairobi, 2014) and Science & Technology Park at the University of Nairobi, and later proceeded to start Gearbox, the first private makerspace in Kenya (Birkelo, 2017).

Kenya is home to at least eight makerspaces, with four in Nairobi, one in Kisumu, two in or around Mombasa (Baarbé & Nzomo, 2017) and one in Eldoret. More makerspaces are in the pipeline, with both Kenyatta University (Directorate of Innovation, 2019) and Jomo Kenyatta University of Agriculture and Technology (JKUAT) (Mburu, 2018) planning to commission their creation hubs in future. Some of the notable local maker centres include Gearbox, Fablab Nairobi, Fablab Winam, Fablab Kivuli and the University of Nairobi's Makerspace. All these makerspaces are located in universities, manufacturing parks, community centres, or incubation hubs.

2.2.6.1 Gearbox

The gearbox is a for-profit makerspace that gives inventors and innovators from diverse backgrounds a platform to prototype and build their projects using shared digital fabrication tools (Gachigi, 2015). The gearbox was started in 2013 by Dr Kamau Gachigi, operating from a shipping container at iHub. Then moved to Industrial area where it hosts private office spaces, shared coworking space, a design lab, classroom, event spaces, and shared workshops (Birkelo, 2017). They offer tech-support, training and co-location (makerspace) services at a monthly fee (students – Ksh. 1000, gear memberships between Ksh. 4000 – Ksh. 10,000, depending on time spent at the makerspace).

2.2.6.2 Fablab Nairobi

Fablab Nairobi is part of Fablabs' global network of local labs. It is located at the University of Nairobi's Science and Technology Park; Department of the mechanical engineering building. The Fablab serves as a rapid prototyping centre with tools and skills to make almost anything (Stacey, 2014). The Fablab serves an important technology transfer function as an incubation space for ideas, preparing them for the market (University of Nairobi, 2014).

2.2.6.3 The University of Nairobi's Makerspace

The UoN makerspace was started in 2009, to accelerate and incubate innovations developed across the university for commercialization. The UoN makerspace, initially located at the school of Engineering's mechanical engineering department, was moved to CAVS, Upper Kabete Campus, Nairobi County, due to the increased demand for more space to house more machinery and equipment. The makerspace contains Laser cutters, 3D printers, CNC milling machines, and Vinyl cutters for prototyping (Mugasia, 2018).

In line with its core mandates, the UoN makerspace offers training services to students and other members to enhance capacity and facilitate them to use the available machines. The facility also offers training on 3D printing, microcontrollers, Arduino, CNC machining, programming and Computer-Aided Design (CAD) to new users. This training was very beneficial to the researcher; he undertook a three-month training on CAD for 3D printing in 2018.

The Makerspace also conducts workshops like the hackathon (renamed Makerthon), quarterly together with industry partners to promote a cross-disciplinary approach to problem-solving and innovation. The hackathon helps build the capacity of teams to design possible innovative solutions through learning by doing (Mugasia, 2018, p. 6).

2.3 Makerspace Users

Makerspaces thrive on the creativity and imagination of makers who use the spaces. They rely on the interests of the makers, providing them with space and tools to actualise them (Kemp, 2013). Makers bring the spaces to life. Makerspaces serve two distinct users, the *makers*; who directly use the space and the *product end-users*; who are the target market of the solutions that come out of the makerspaces.

2.3.1.1 Product End-Users

A product end-user is the consumer of a good or service, the person that uses a product (Kenton, 2019; Suttle, n.d.). The term is used to differentiate the person who buys and uses the product from individuals who are involved in design, development, and production stages.

Although these users are important, their experience can be slightly distorted due to their attachment with the product, compared to the end-user experience. For this study, these are the intended users of the products or solutions that are created at the makerspace. This category of makerspace users is broad and tends to vary from one project to another. They, however, were not considered part of the scope of this study.

2.3.1.2 Makers

“We are all born Makers”(C. Anderson, 2012, p. 13). As Anderson puts it everyone can become a "Maker". But who exactly is a *maker?* There is no set definition for a maker. Makers mean different things to different scholars. Van Holm, (2014) terms it as extremely vague, he opines that a maker can be "an individual building a 3D printer from an online guide, but can also be someone cooking a family meal or a computer scientist creating a new web service." Hence all of us are makers (Dougherty, 2012). Halverson & Sheridan (2014), however, dispute this noting that not all the persons involved in movement automatically take on identities of involvement within the maker scene.

According to Kalil (2013) makers are people who design and create objects because they find it innately rewarding to make, tinker, problem-solve, discover, and share what they have learned" (p. 12). Michelle *et al*., (2013) portrays makers as "enthusiasts who play with technology to learn about it". According to Martin (2015), a maker is a person who builds things, while being creative, having fun, to solve problems, hence do good, as they collaborate and learn. Broadly, makers are individuals who have embraced the maker culture. The Maker culture is a global movement of individuals using digital fabrication, open hardware and software to innovate with an aim of openness and skill transfer as opposed to commercial gain (N. Taylor et al., 2016). For this study, *a maker is an individual who utilises a makerspace to build and create.* They are the key stakeholders in the makerspaces.

Makers have access to prototyping technologies and digital fabrication tools for rapid prototyping while working alongside other makers, sharing knowledge, skills and designs (C. Anderson, 2012). In line with the *"Maker Movement Manifesto",* Makers use the makerspace to *Make*, *Share* what they have made and what they know about making with others, *Give*, *Learn*, *tool up*, *play* and *participate* (Schön *et al.*, 2014). In makerspaces, makers are often intrinsically motivated to use the space. As Farritor, (2017) notes, the makers are often self-motivated to solve problems, hence leading innovation. The need to create new products and solutions pulls people to creation hubs as opposed to external push like work or school assignments.

The typical makerspace users in Africa tend to young male university graduates with a background in IT, Engineering or other creative skills (Njambi-Szlapka, 2019). This was the same case at the UoN makerspace. The majority of the makers using the UoN Makerspace were predominantly male students taking engineering courses. In their study *"An exploration of women's engagement in Makerspaces"* (Bean *et al*., 2015) noticed the same trend in the USA; 81% of U.S. Makers were male, indicating that there is gender inequality in makerspaces.

Makerspaces are about people, the community of users who conduct activities in the spaces, despite their importance, the researcher found very limited academic publications on the human component of the makerspace. Previous studies have focused on the resources, tools and activities that go on inside the makerspaces. To bridge the gap the researcher looked in depth the people who make use of makerspaces. Makers usually have differing experience levels working with diverse media, but what is common among them is making. They develop ideas and build them into some physical or digital form (Sheridan *et al*., 2014). The researcher looked at some of the makers part of the maker movement.

Enthusiasts and Hobbyists

Makerspace enthusiasts and hobbyists are users who are essentially playing with technology (Dougherty, 2012). They have access to the tools in makerspaces to experiment with them. They use the available tools to make things, take them apart and put them back again. Through that, they manage to learn, repair and utilise the available tools. The maker movement attributes its origins to these users. Dougherty (2012) notes that "Today's makers enjoy a level of interconnectedness that has helped to build a movement … by a particular hobby or activity... connected by the enthusiasm and a common passion" (p. 12) from the initial *Maker Faires*, enthusiasts and hobbyists have always graced these gatherings (Thilmany, 2014). The tech enthusiasts and hobbyists are often involved in hobbies and crafts like woodworking, sewing and electronics and more recently in digital fabrication (Martin, 2015). These users are normally unattached to any organisation, using the space out of their free will.

Tinkerers

Tinkerers are makers who build something out of existing, available parts for new purposes (Foege, 2013). They have a passion and an obsession to disrupt the status quo, leading to the creation of novel solutions. In makerspaces tinkerers can be seen taking apart electronic gizmos, to create robots, 3D printers and other innovative appliances. Makerspaces offer a conducive environment for tinkerers to casually play with product design aiming to improve or repair them (Matias & Rao, 2015). Mildly, tinkerers include anybody with ideas take time to explore them. Evidence of tinkerers can be traced to the RepRap project (in 3D Printing), an open-source community that enables users to build personal 3D printers. The world-famous MakerBot printer is a result of tinkering (Matias & Rao, 2015).

Researchers

These are academic researchers conducting their studies in the confines of the makerspaces. These scholars are either studying how the maker movement work or are working on their projects using additive manufacturing tools like 3D printing among other tools. These users can be active participants in the makerspace or be passive users, observing the different process. The researcher has for the past two years been embedded at the UoN Makerspace taking part in some maker projects.

Students

Makerspaces are a new frontier in the academic sector with educators utilising them in project-based learning. In higher education, especially in engineering, academic makerspaces are an important development (Wilczynski, 2015). To promote design experience among students, universities have turned to makerspaces (Forest *et al*., 2014).

Students make use of makerspaces for academic, extracurricular and personal undertakings alongside their peers with help from faculty and staff. They use design software, manufacturing tools and integrated control systems to prototype and make finished products. Makerspaces in universities are a shift in approach to a "bottom-up" knowledge where, students discover by doing then share as opposed to classroom and lecture-method (Wilczynski, 2015).

At the Georgia Institute of Technology's invention studio, through a student-driven approach, students from all levels and disciplines have access to design and manufacturing equipment. At the invention studio; a student-run design-build-play space, the undergraduate students also take up the added role of supervising the other users as student volunteers (Morocz, 2016). The students are not paid, they, however, receive more access time than normal students are allowed and are eligible to apply for project grants (Galaleldin *et al.*, 2016).

Faculty

This a body of educators; professors, lecturers and research assistants who utilise the makerspace to educate or are in charge of the makerspace. At makerspaces like Northwestern University's Segal Design Institute where makerspaces have been fully integrated into programs (Bachelor of Science degree in Manufacturing & Design Engineering, Master of

Science in Engineering, Design & Innovation and Master of Product Design & Development), the faculty conduct their lessons within the facilities (Wilczynski *et al.*, 2017).

Staff

These are the makers who are hired to work at the makerspace. They maintain, arrange and clean the makerspace and the machines among other roles. These users work with the equipment daily and often offer assistance to other users from time to time. Though they are rarely acknowledged in research, they play a very important role, ensuring that the spaces run smoothly without hitches.

In most community makerspaces they hire professional personnel, but in university makerspaces, they enlist the services of graduate assistants, student staff and full-time staff; that can include faculty or not. They are responsible for all aspects of operating the makerspace, including an admission of new members, training, repair, maintenance and organising the makerspace's programs (Wilczynski, 2014). They also act as design mentors, assisting individuals and teams to design and build solutions and are often available for consultation and at hand to help when the makers are stuck.

Management

Different makerspaces employ different ownership models, hence different management models. The owners normally dictate the model that is used, for instance, university makerspaces are often led by faculty. *The Yale Centre Engineering Innovation and Design* and *The Segal Design Institute*, for instance, courtesy of their location in the university are led by a tenured mechanical engineering faculty member (Wilczynski, 2014).

Privately owned for-profit makerspaces on the other hand, are operated by directors who established them. The gearbox is directed by Dr Kamau Gachigi, one of the founding partners of the space (Birkelo, 2017). Community makerspaces like the Dundee Makerspace do not have formal management structures, but rather operate collectively, with select members playing the managerial role (N. Taylor *et al.,* 2016).

Donors

Although they are not involved in the day by day making process, donors play a very important role and can be considered as makers, because they dictate the making process in makerspaces. Makerspaces require funding to operate optimally. While most makerspaces are embedded under large organisations like schools, companies or universities, get their funding from the mother organisations, they need sustainable sources of funding. These funds come from donors who invest their resources to support research or projects in the form of grants. For instance, the New York Hall of Science received a grant in 2011/12 for a makers project and a learning lab within the Cognizant Maker Space (Institute of Museums and Library Services, 2014). Other beneficiaries of the IMLS-Funded maker projects include the Idaho Commission for Libraries, the Westport Library ($246,545), the Oregon Museum of Science and Industry ($100,00), the Chicago Public Library ($249,999).

Donors also help set up makerspaces, cover staffing costs and buy equipment. Through grants and scholarships, they keep the lights on. Not all donations come in the form of money, some donations are in the form of equipment. The gearbox is an example of a makerspace that started as a "shop in a box" from a shipping container full of tools donated to iHub in 2013 (Birkelo, 2017).

Clients and Incubations

Makerspaces cannot rely entirely on donations and grants for their day to day operations. They have to find sustainable sources of funding to keep their lights on. Hence most makerspaces have opened their doors to clients and start-ups who use their facilities and equipment at a fee. Through start-ups or service investment opportunities, makerspaces develop a sustainable revenue model to cover the overhead costs and dependency on the mother-companies or grants (Crumpton, 2015). The *Tshimologong* Makerspace in Johannesburg runs an incubator program that provides digital entrepreneurs with tools to test their concepts and grow sustainable businesses. They also provide an open and collaborative coworking space with fast internet, Printing, training, conference rooms and office support to companies at a fee (Tshimologong, n.d.). The gearbox has a similar program where they offer tech-support, training and co-location (makerspace) services at a monthly fee (students – Ksh. 1000, gear memberships between Ksh. 4000 – Ksh. 10,000, depending on time spent at the makerspace) (Birkelo, 2017).

2.4 Methods: Making and the Making Processes

Makerspaces operate under the basic framework of thinking-making-and-sharing. Under thinking; planning, sketching, research, discussions and interviews take place. The actual making entails stitching, assembling, printing, cutting, drilling, measuring, coding, tinkering etc. to create a tangible solution. Finally, the solution is shared with the world. This is done through; documentation, design, depiction, narration, display, engaging users and testing. The researcher looked at the making processes that are used at academic Makerspaces to generate solutions, create products and services.

2.4.1 Making

Making is a broad term, meaning different things to in different scopes. It essentially is the act of creating something (Good, 2013). It has been around for as long as man has created things so have the spaces where making happens (Wong & Partridge, 2016). To understand making in makerspaces, I draw from the literature on making from both technical and creative spaces.

Vuorikari, Ferrari, & Punie, (2019) in their report *"Makerspaces for Education and Training Exploring future implications for Europe"* identify scenarios where making will happen; these include; a) Making as a learning space, a methodology, a community and as a life skill. Making as a learning space looks at makerspaces at educational settings for goal-directed and intentional learning while making as a methodology the emphasis is on the processes used to create. Making as a community explores the making mindset that is shared by the maker movement whereas as a life skill focus is on the individual motivation and interests of the makers.

The subsequent sections focus on making as a methodology, looking at the processes used in making (creation) at university makerspaces and how they are used.

2.4.2 Engineering Design Process

Projects at Makerspaces employ the engineering design process to solve design problems. This is a series of steps that are applied by engineers for product development. Making process starts with the receipt of a brief. Design teams identify the design needs and constraints. Then, they conduct problem research to develop potential solutions. The solution with the greatest potential is then selected for prototyping, testing and evaluation. Finally, the team improves the product as needed (Cooper *et al.,*, 2008).

Figure 4: Engineering Design Process. (Source: Adapted from Khandani, 2005)

The engineering process is a five-step process that starts with a) problem definition, b) Information Gathering c) Generating Multiple Solutions d) Analysing and Selecting the best Solution and finally e) Solution testing and implementation (Khandani, 2005, p. 11).

Problem Definition - This is the initial step in the process. According to Khandani, (2005) problem definition entails highlighting the product and the customer needs the product's features and functions. The design problem has to be clear and unambiguous. In this phase, the need for the solution is identified and established. Next, the problem Statement is developed. Finally, they establish the criteria for success.

Information Gathering: Khandani, (2005) emphasises the need to gather the information that is available on the solution. This entails the market research, information on the competition, availability of products that already solve the problem. This is done by searching information resources like the internet (google), checking out traditional publications like encyclopaedias and technical handbooks among other sources.

Generation of Multiple Solutions: This stage, seeks to utilise creativity to generate new ideas. The engineering process advocates for synthesis; The process starts with taking the existing solutions, analysing them to establish the weaknesses and finding ways to solve them (Khandani, 2005, p. 11).

Analyse and Select a Solution: After generating alternative solutions to the design problem, the team then gathers to analyse the solutions and decides the best solution for implementation. The proposed solutions are analysed in-depth to decide which solution should be carried out. All the solutions are analysed based on functional analysis; ergonomics; electrical components; the manufacturability; product safety and liability; market analysis and whether they meet regulatory and compliance structures (Khadka, 2015). After the analysis, the team decides which solution is the best. The solutions are evaluated objectively against the design criteria using a design matrix (a mathematical tool).

Test and Implementing the solution: The last phase of the engineering design process is the application phase. This can be testing, constructing or manufacturing the solution. After testing the design goes to production. The team then undertakes documentation where they document their work, clearly document the solution to the design problem for others to understand the solution. They incorporate graphs, charts, visual elements like manuals, PowerPoints, sounds, videos and animations depending on the project budget.

In this process, the user is first involved after the prototyping and testing phase, to test whether the product works. Though their feedback is incorporated in the redesign of the product, their input is sought to improve the product without factoring in their needs. The process assumes that the user requires the product and goes ahead to create a solution for them. Their role is to test whether the solution works as opposed to whether it works for them. In most cases, the user will interact with the product when it is launched to the market. Hence many products using this process tend to fail in the market and can lead to massive losses (Norman, 2013, p. 234).

The engineering process is linear, (also called the waterfall method). As opposed to the Human Centred Design process with is iterative; circular with back and forth, it is a one-direction process making it impossible to go back and change components (Norman, 2013, p. 234). Norman proposes a gated method that combines both HCD and the engineering process.

2.4.3 Human-Centred Design

Human-centred design (HCD) is a process of "*designing for people*" (Babich, 2018). HCD seeks to "develop solutions to problems by involving the human perspective in all steps of the problem-solving process" (Kuijer & De Jong, 2011). HCD operates under the notion that "*answers to problems faced by the users are held by the users themselves*", hence seeks to deeply understand the users before embarking on designing a solution for them (IDEO, 2015).

Human-Centred design is an iterative, measurable and results-driven approach to problem-solving (Dalberg, n.d.) based on communication techniques where the designer interacts and empathises with the user. When using HCD, the designer strives to get insights from the users' needs, pains and experiences, using the user's values and self-beliefs (Giacomin, 2014: 610).

2.4.3.1 The Guiding Principles

Although there are no universally agreed standards, scholars in Human-Centred Design agree on some guiding principles.

People-Centred: Human-Centred Design seeks to focus on the people being designed for and is based on observed, human need (Babich, 2018; Klein, 2016). It advocates for identifying the real users and seeking to design solutions that are focused on their needs, strengths and aspirations. It means starting with the needs and the abilities of the people (Norman, 2013, p.

218). To create applicable solutions, there is a need to understand the challenges and opportunities that users encounter in their normal lives (Design Council, 2019).

Finding the right Problem: The ability to distinguish the fundamental problem from the symptoms of problems (Norman, 2013). Designers have to understand what the real issues are, before proceeding to solve them. Don Norman identifies the tendency to solve symptoms of the problem as opposed to tackling the core problem.

Thinking everything as a System: Human Centred Design process requires designers to focus on the entire activity, to look at the bigger picture (Babich, 2018); the intended outcome of the exercise. This ensures that the user experience is achieved at all phases of the design exercise. When applying the Human Centred Design process there is need to think about the whole journey of the product (Townson, 2017), you have to go beyond the user of the primary user and look at the general ecosystem where your solution is going to be used.

Rapid Iteration, Prototyping and Testing: Human-Centred Design leverages continuous learning. Solutions present an opportunity to observe those who use it, their experiences, and the challenges and opportunities it addresses. These key insights are then used to further enhance and develop the solution (Klein, 2016). These allow for early and rapid iteration lowering the risk and build conviction in your ideas. Human-Centred Design requires the team to test the solutions with the "real" user who will provide feedback for further improvements (Design Council, 2019).

The International Organization for Standardization, in their ISO 13407 summarised Human Centred Design in four principles: "a) The active involvement of users and a clear understanding of user and task requirements; b) An appropriate allocation of function between users and technology; c) Iteration of design solutions; d) Multi-disciplinary design." (Steen, 2008, p. 20)

The first and last principles are of interest in this research. The ability to focus on the people one is providing a solution for, based on observed, human need (Babich, 2018; Klein, 2016). The need to identify the real users to help come up with solutions that are focused on their needs, strengths and aspirations. It means starting with the needs and the abilities of the people leading to solving the " right problem" (Norman, 2013, p. 218). The multidisciplinary nature of teams is also of interest because the maker movement has based its existence on the need for makers from different disciplines to work alongside each other. Of interest is how projects are conducted in the making process at the makerspaces. However, for this study, the user is the maker as opposed to the end-product user.

2.4.3.2 Human-Centred Design Models

There are three major models used in the Human Centred Design process. The double diamond model (Design Council, 2019), the IDEO Design Model (IDEO, 2015, p. 11) and the Stanford d.school model (Plattner, 2010). There are, however, other design models that are industry-specific, like the Evolution 6^2 Mindshake Model by Katja Tschimmel and the FORTH innovation Methodology by Gijs Van Wulfen that are commonly used in business (Ganova, 2017). The three models were picked for their prevalence, origins and multiplicity of implementation fields.

2.4.3.2.1 The Double Diamond Model

The double diamond model is a decision-making approach that pairs divergent and convergent thinking, to make effective choices through an in-depth understanding of the challenge and possible solutions (Klein, 2016, p. 2). In the divergent phase, teams work to collect information to acquire maximum insights. In the convergent phase, the gathered information is examined, organized and filtered based on the objectives (Klein, 2016, p. 2).

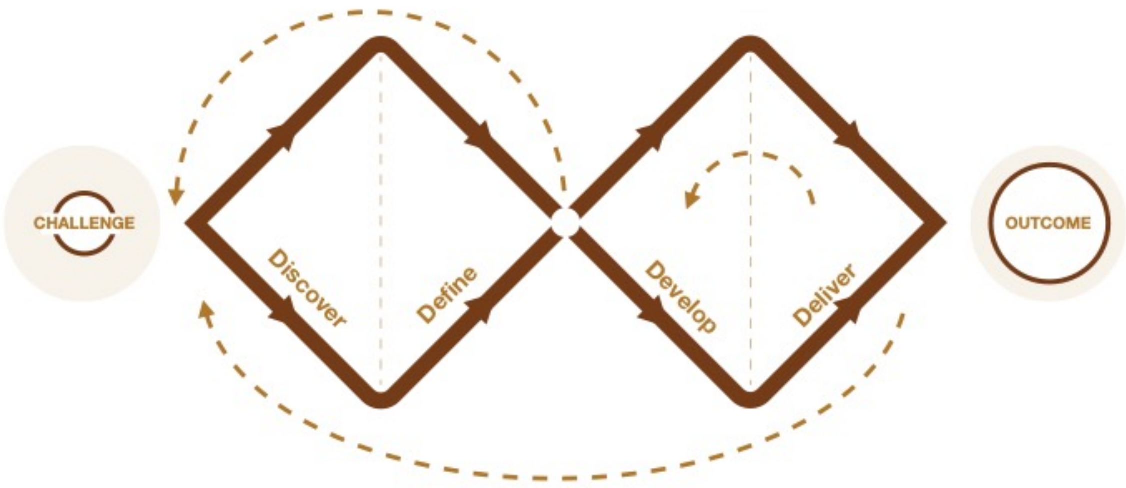

Figure 5: Double diamond model by Design Council. (Source: Design Council, 2019)

2.4.3.2.2 The IDEO Design Process

The IDEO design process, unlike the double diamond, utilizes three broad phases (Inspiration, Ideation and Implementation) for problem-solving (IDEO, 2015, p. 11). At the inspiration phase, the designer observes the users for key insights. The Ideation phase involves creating several ideas based on key insights from the inspiration phase. The opportunities for design are identified and tested to refine the solutions. The implementation phase involves bringing your solution to life, preparing it for the market or the real world.

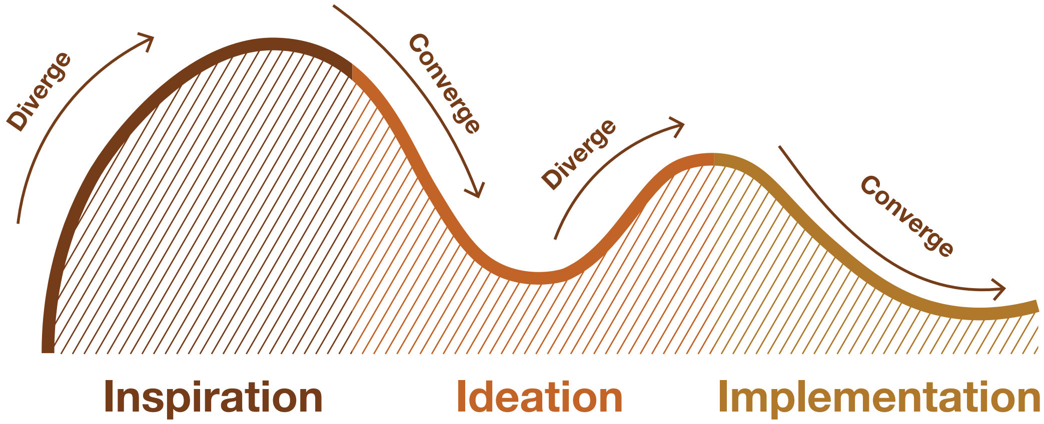

Figure 6: IDEO Design Process. Source (IDEO, 2015, p. 15)

2.4.3.2.3 The Stanford d.school design thinking process

The d.school model proposes five stages of Design Thinking; *Empathy*, *Defining the problem*, *Ideation*, *Prototyping*, and *Testing*. The d.school model though articulated as a linear progression is an iterative process and more flexible and non-linear in practice (Dam & Siang, 2019; Plattner, 2010).

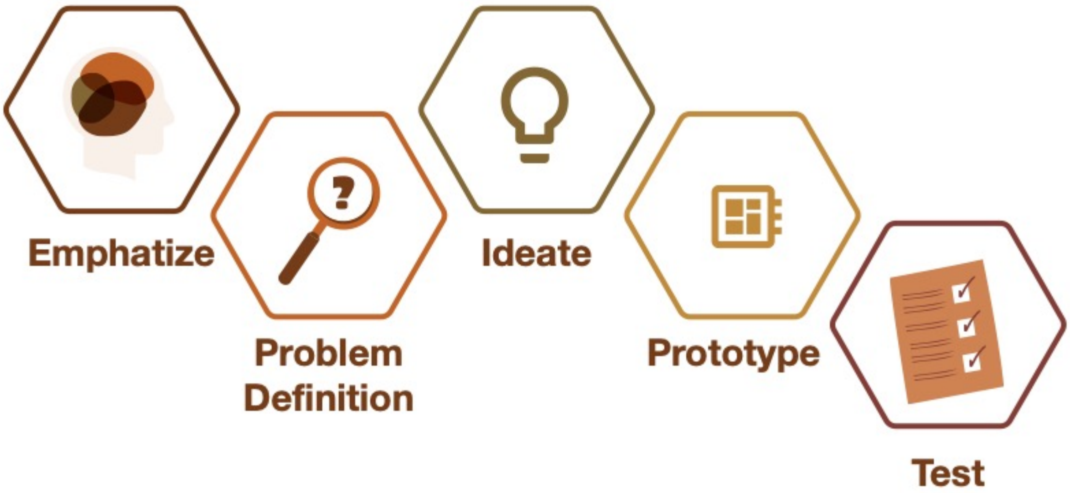

Figure 7: Stanford d. school model (Adapted from Stanford d.school)

Empathise: The Human-Centred Design process starts with emphasising; understanding people in the context of the design challenge. Designers seek to understand how and why users do things, their needs, how they view the world, and what they hold important. Through observation and interviews, designers engage with users directly observe their needs, gathering insights that will help create innovative solutions, based on understanding the beliefs and ideals of the user (Plattner *et al.,* 2011).

Define: The design team then defines the problem to bring clarity and focus on the key challenge. The right problem is framed to create the right solution using insights from the empathy phase (Dam & Siang, 2019). The output of this stage is an actionable point-of-view resulting from key insights and needs of the user (Plattner, 2010).

Ideate: In the ideation stage, brainstorming, mind mapping and sketches are used to generate as many ideas as possible. At this point, no idea is bad, as judgement is deferred. The emphasis is on generating ideas as opposed to the evaluation of the ideas (Dam & Siang, 2019).

Prototype: The process moves to the prototyping stage where artefacts are created for initial feedback from users and colleagues. Low-resolution prototypes are created in the initial stages, that are quick and cheap, to allow for feedback without using a lot of resources (Hasso Plattner Institute of Design at Stanford, 2016).

Testing: Testing phase is the final stage of the d.school process. This stage entails testing prototypes with multiple users, getting feedback during testing and turning the prototype into an experiment to see how users interact with the concept in real life. This phase can result in redefining the problem, understand the user or refining the prototypes and solutions (Plattner, 2010).

2.4.3.3 Different Methodologies

There several ways of conducting Human Centred Design used in Makerspace projects. In the following sections, I identify and discuss three methods of organizing and conducting that are applied in academic makerspaces. These vary with the traditional approaches; Participatory design; Applied ethnography; Lead user approach; Contextual design; Co-design; and Empathic design by Steen (2008, p. 31). They offer procedures of utilising Human Centred Design to develop solutions.

In academic Makerspaces, due to existence of different activities, different disciplines use different approaches to actualise Human Centred Design. Software leaning makers make use of the agile development cycle (Sharma *et al.,* 2012) that focuses on delivering high-quality software go through the collaborative effort between teams and their users (Muslihat, 2018). The agile approach makes use of sprints and is open to changes focusing on continuous improvement. The approach emphasizes on small modules to allow for early detection and fixing of bugs (Sakovich, 2018)..

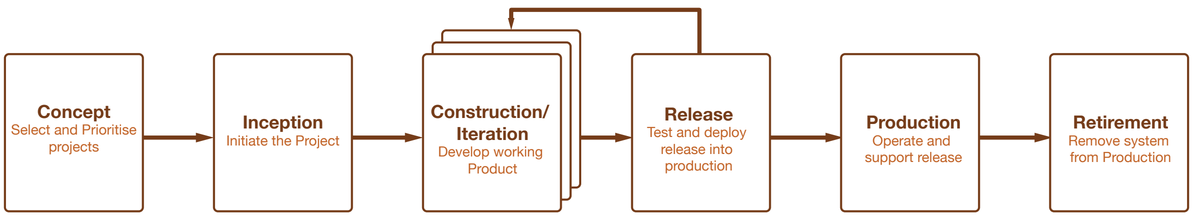

Figure 8: Stages of the Agile Process (Source: Lucidchart, n.d.)

Engineering teams, on the contrary, employ the lean approach, an improvement and problem-solving methodology that seeks to reduce waste that does not add value to the user. Initially used in manufacturing, the lean concept is attributed to the Toyota owner Kiischiro Toyoda and engineer Kaiichi Ohno in the 1930s (Miletić & Miletić, 2017). Through the principles of lean approach, they developed the Toyota Production System considered one of the machines that changed the world (Womack *et al.,* 2007). Due to its efficiency in manufacturing the lean concept has found its way into other industries including business, economics, management, tourism, Healthcare and design. The lean approach is well suited for the product development process in makerspaces given its focus on lowering overhead costs and maximizing on efficiency in prototyping.

The researcher, however, opted for a methodology that can be applied across all the activities in a makerspace. For that reason, the design sprint was selected, unlike the previous methodologies, it is applicable in multidisciplinary segments and is relatively easy to apply in product development.

2.4.3.3.1 Design Sprint

The Design Sprint is a five-day process developed by Jake Knapp that employs design thinking to lower risk when developing a new product for the market (Knapp *et al.,* 2016). It entails solving problems through design, prototyping, and testing ideas with users to create solutions quickly. Southall and team summarise the design sprint as "a pragmatic tool for rapid production and testing of design prototypes, designed to reduce the resources needed to produce the final solution, avoiding the expensive user involvement mistakes" (Southall *et al.,* 2019, p. 60). It is a shortcut to learn about the solution without building and launching, cutting on cost and time.

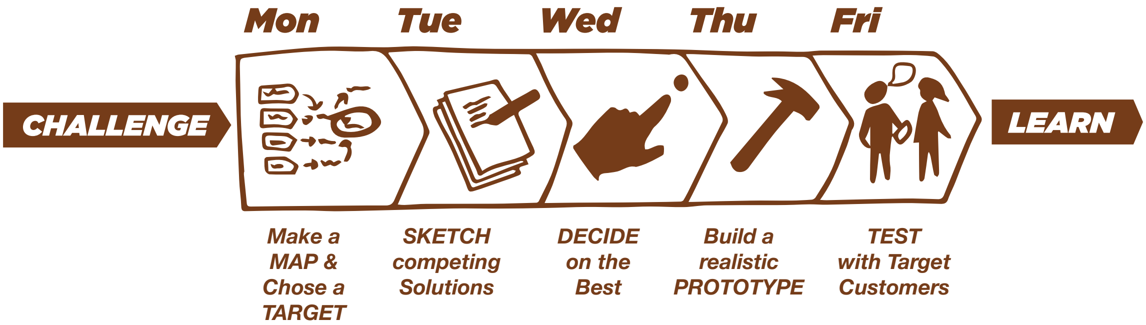

Figure 9: Design Sprint (Source: Medium)

The design sprint takes a small team (5-7 members) over a week and rapidly progresses from the problem to the tested solution. *Day one*, the problem is mapped, *Day two*, each member sketches their solutions, *Day three*, the team decides which is the best solution; *Day four*, they build a realistic prototype and on the *last day*, they test the prototype with five target users (Knapp, 2016).

The exercise begins with the recruitment of a team of experts (seven people or fewer) with diverse skills along with people who work on the project day today. This ensures that all the key persons are involved. The participants are intentionally and selectively recruited based on the goals of the design sprint (Margolis & Zeratsky, 2015). Once space and the materials (e.g. whiteboards, sticky notes, whiteboard markers, felt-tip markers, pens, paper, masking tape, dot stickers and time timers) have been secured, the design sprint can start.

Day 1: Understand: The first day of the design sprint entails a series of structured discussions meant to create a path for the sprint week. The team agrees on the long-term goal, then maps the challenge. The experts then share what they know before picking an ambitious but manageable target from the problem that can be solved in a week.

Day 2: Diverge / Ideate / Sketch: The second day dwells on solving the problem using deep thinking. The team focuses on solutions. The existing ideas are reviewed to act as an inspiration for the team. This is then followed with intensive individual sketching sessions. At this point the emphasis is on critical thinking as opposed to artistry, the sketches do not have to perfect sketches.

Day 3: Converge / Decide: The third session starts with getting solutions for selection by the team. Due to the variety of solutions, the team has to select the solution that can be prototyped. They critique the available options before settling on the best solution. The selected solution is then weaved into a storyboard for the prototype.

Day 4: Prototype: This phase entails building a realistic prototype of the solutions based on the storyboard. The design sprint advocate for a "Fake it" principle to turn the storyboard into a prototype. This prototype is what will be used to test with the users. The recommended prototyping tools include marvel, in vision and even using a 3D Printer to 3D print a tangible solution.

Day 5: Test: To conclude the design sprint the team seeks to obtain essential feedback on their solution. The Google Ventures (GV), team advocates for 1on1 interviews to evaluate the prototype but this can vary from on development product to another. The team can also learn by observing the user while they interact with the product (Knapp *et al.*, 2016). The aim is to get as much feedback as possible, which can be then summarised as real-time findings for further development and iteration on the solution. Testing the prototype helps the team to refine the solution and determine if they are solving the right problem or not.

The design sprint brings the key stakeholders together, shortens the development process and is faster than the traditional design thinking processes like the IDEO, Stanford d. school and co-design processes. It compresses the process to a week, ensuring that the teams can be able to quickly prototype and test their solutions in a week. Hence quickly identifying the gaps saving valuable time. Strengths of the Design Sprint lies in the rapid prototyping and multidisciplinary nature of the process, the ability to bring all the stakeholders together in a record time has made this process preferable to key experts. This process, however, has been criticised for being expensive requiring significant investment for organisations since key people have to clear their schedules during this period (Vetan, 2019). This has led to iterations to create more efficient Design sprints like the *Design Sprint 3.0* by the Design Sprint Academy.

2.5 Human-Centred Design in Makerspaces

A big part of Human Centred Design is building, testing and iterating prototypes (Rendina, 2019). Makerspaces are essentially prototyping spaces; they involve building and testing prototypes to create novel solutions. Makerspaces are the perfect places for Human-Centred Design because they offer access to a variety of tools and materials for prototyping.

Waldman-Brown *et al.,* (2016) note that HCD is a popular tool for the development of empathetic innovations through the collaborative development of relevant and locally-appropriate technologies. They allude that most Makers employ similar techniques when inventing or improving technologies without even realising the similarities. There are few explicit links between Human-Centred Design and the Maker Movement as a whole.

Makerspaces are created on the tenants of making, creation, design, and innovation (Peppler & Bender, 2013). They offer infrastructure to support innovation, openness and collaboration. Design thinking is an innovative approach that draws from the user's needs blended with technological possibilities to solving wicked problems. Design thinking gives maker projects a framework that helps makers build empathy for the end product-users, it helps them look beyond their own experiences resulting in better designs that work for the user (Rendina, 2019, p. 3).

When used in makerspaces, Human Centred Design can help spark innovation, fire imagination leading to innovative solutions that keep the user at the centre of the solution (Agrawal, 2017). Hughes *et al.,* (2019) reaffirm this in their study *"Makerspaces Promoting Students' Design Thinking and Collective Knowledge Creation: Examples from Canada and Finland"* where they found out that when used in makerspaces, design thinking can help build students' competencies offering a creative approach to knowledge creation.

2.5.1 Makerspaces using Human-Centred Design Exemplar: The Segal Design Institute

The Segal Design Institute, at the North-western University, was used as an exemplar due to its primary focus on Human-centred design projects (Wilczynski, 2015). Segal Design Institute, primarily utilises Human Centred Design, with a focus on design innovation for problem-solving. Projects conducted at the institute utilise empathy to solve complex problems. As opposed to addressing symptoms, they use a human-centred approach in what they call "getting at the heart of what matters" to identify the user's fundamental issues hence humanising innovation (Langen, 2019).

The Segal design institute uses a threefold approach to design innovation; mindset, process and tools. Projects at the Segal institute focus on the design teams' mindset, incorporating empathy, persistence, humility, collaboration, optimism and imagination as the key design mindsets. The process is tinkered to centre the user throughout the creation process. The design teams employ tools that allow the designer to frame opportunities that go beyond solving the problem. Tools that allow for the identification of the root of the problem, not just the symptoms. This helps the designers to avoid solving the "wrong problem". The focus, in this case, is being able to give and receive feedback to make the solution better. The design innovation tools used at the institute for this purpose include; research safaris, storyboards, Cardboard Mock-ups and 3D printing for prototypes, service blueprints and user panels maintaining contact throughout the process (Segal Design Institute, 2018).

The *Prima Vita*

Figure 10: Prima Vita an infant formula feeding solution appliance. (Source: Segal Design)

The *PrimaVita™* is an example of a product that was made the Segal Design. The *PrimaVita*™ is "a compact and user-friendly infant formula feeding solution appliance" (Boros *et al.,* 2018) designed for positioning with other small appliances in the kitchen shelves. It can run on batteries or with a cordless cable. As part of their empathy mapping, the project team identified Product Opportunity Gaps (POGs), through researching users in their setting to create ethnographies to for distinct user needs and pain points (Boros *et al.,* 2018).

The next phase entailed exploring the practicability, viability, and attractiveness of solutions in each space, and narrowing their focus to *"small appliance-based"* kitchen solutions. The market research tools used to understand the competition and identify potential market segments of target users included interviews, surveys, and data analytics.

Two design solutions were identified after numerous rounds of iterating design concepts, rapid prototyping, and extensive consumer feedback. The final design direction was reached with help from the potential users. The group then filed for a provisional patent for the Intellectual property rights before creating the final 3D printed prototypes for presentation to potential investors.

From the processes at the Segal Design Institute, a clear application of the HCD process can be identified. The facility sets a precedent that can be applied to projects at the UoN makerspace to make human-centred solutions.

2.6 Tools and Materials

Makerspaces, without tools and materials, are just spaces, to build and create, makers rely on machines and equipment that is otherwise too expensive to acquire individually. Tools make it possible for makers to create, destroy, hack and manipulate things (Kemp, 2013, p. 23). Makers not only need the right tools to make the jobs easier but also need to have a good understanding of proper use and care of the tools.

A standard makerspace includes a range of tools, equipment and materials that are communally shared. Fab Labs propose a basic set of core tools that a makerspace must have to actively participate with the global network (Karre *et al.,* 2017). These include a laser cutter, a CNC mill, a Vinyl Cutter, a 3D-Printer, an electronic workspace with a soldering station and test equipment, and a communication network with a video conferencing kit.

The type and number of tools and materials needed in makerspace depend on the size of the makerspace, the foot-traffic and the type of makers who they seek to attract or who use the space. Tools, equipment, machinery and materials required in makerspaces can be grouped into five broad categories; Digital Fabrication tools, Handcraft tools, Power tools, Brainstorming tools and Software.

Digital Fabrication tools are tools that are controlled by a computer (Jorgensen, 2019). The most common forms of digital fabrication include CNC machining tools (cut shapes out of wooden sheets), 3D printing (things are built layer by layer) and Laser cutting that uses a laser beam to cut materials. These tools in most makerspaces include 3D printers, laser cutters, electronics and soldering, Wielding Vinyl cutting, milling among others.

Handcraft tools are tools that are powered manually (OSHA, 2002); with the physical strength of the makers. They are often used in operations like woodworking and textiles using tools like needles, glasscutters, spinners, hand planes, hack saws, files, cutters etc. and can include anything from axes to wrenches. Hand tools work with limited power with reduced noise. The materials used for handcrafts are only limited by the craftsperson's imagination (Xaxx, n.d.). When working with hand tools makers must wear appropriate protective equipment like safety goggles and gloves to protect against hazards (OSHA, 2002).

Power tools require an external power source other than manual labour to run (Department of Training and Workforce Development & Russell, 2016). Power tools, come in different types depending on the power source they use. They include electric, pneumatic, liquid fuel, hydraulic, and powder-actuated tools. Common power tools in makerspaces include air compressors, shears, grinders, saws, sanders crushers, heat guns, trimmers, wrenches, blowers, scalers, tillers etc. If used improperly, power tools can be hazardous, hence makers require training on the use of all power tools, to help them understand the potential hazards and the mandatory safety precautions to prevent those hazards from occurring (OSHA, 2002).

Brainstorming and Design thinking tools are tools that aid in knowledge gathering and dissemination. These are fairly recent additions in makerspaces, intending to incorporate design thinking in makerspaces. They include visualisation tools like whiteboards, sticky notes, whiteboard markers, felt-tip pens, tapes etc. These are used in the brainstorming sessions for idea generation and conceptualization. First used at Stanford's d.school, these tools are becoming popular in makerspaces with more spaces setting aside spaces and tools for brainstorming sessions.

Software – Makerspaces require a variety of software to prepare files for machines. Due to the modernisation of makerspaces, the need to design using computers (Computer-Aided Design) and process the products (Computer-Aided Manufacturing) for the machines, makers use software that can support the design and making process. Some of the popular software includes OMAX Make, OMAX Layout, JobControl X, Inkscape, Embird, TinkerCad, Slic3r and Cura 3 among others. Though there is opensource software (like those listed above), others like Solidworks, Rhino, Autodesk, Sketchup, and Adobe Creative Cloud have to be purchased. Some software is machine-specific and is supplied by the machine manufacturer.
Appendix 1, shows a complete list of tools and materials that are required when setting up and running an academic makerspace.

Baarbé and Nzomo (2017) in their *Open AIR's Makerspace Research* noted that although the equipment is available, the makers still lack the skills and knowledge to design products and use these machines to bring their ideas to life.

2.7 Location and Spaces

2.7.1 Creating a Maker Conducive Space

Makerspaces are known to be open environments meant to offer atmospheres that enable people to freely explore, create, build, test and navigate areas of innovative practises through hands-on approaches(Tomko *et al.,* 2017). They are an outlet where "makers" creativity is unleased, utilising the available resources, tools and machinery to design, build and create.

Creative Environments – Makerspaces are set up to offer a suitable atmosphere to inspire creativity and innovation, to foster collaboration and sharing that is central to the operations of the maker movement. There is a need to create layouts that allow makers to utilise available resources effectively. Many makerspaces in one way or another look like studio arts environments, where makers work individually or collaboratively using available provisions to design and create (Sheridan et al., 2014). They have employed the studio structures model by (Hetland *et al.,*, 2013) used for the teaching of digital media and in informal educational environments.

Hynes & Hynes (2018) note that the primary goal of makerspace environments in higher education institutions is to serve a large number of students from multiple disciplines by providing a space where they can innovate and bring their ideas to life. Space has to be inviting to the varied needs of students that the institutions serve. Gender needs and diverse disciplines have to be considered at the makerspace design stage. In addition to that the spaces designated for makerspace activities need to be flexible, well ventilated, allow for noise, fumes, odours from printers, have sufficient electrical outlets, data access and boards for brainstorming sessions (Crumpton, 2015). Flexible spaces and workspaces encourage active engagement by makers and allowing for mobility resulting in teamwork and collaboration in general (Rands & Gansemer-Topf, 2017).

Doorley and Witthoft's *"Make Space: How to Set the Stage for Creative Collaboration"* compiles *Tools*; providing tips on how to build objects, equipment among other things, *Situations*; provide setups and outlines for creative applications, *Insights* and *Space studies*; on the other hand focus on coming up with spaces suitable for making, experiential learning, innovation, and collaboration. Finally, they offer a *Design template*; that showcase collaborative environment (Doorley & Witthoft, 2012).

Safe Environments – Makerspaces house a community of makers, the larger space the harder it becomes to run it effectively and safely (Michelle *et al.*, 2013). Safety and responsibility in makerspaces must be maintained while encouraging freedom, accessibility and creativity. At Georgia Tech's Invention studio, they have managed to do this "through a culture of personal responsibility and self-awareness" (Forest *et al.*, 2014). The studio has strict rules, using student leadership to enhance responsible ethos, for ultimate safety and communal ownership. They have employed a bottom-up safety culture using social-pressure, awareness and unity. This is different from other universities where safety is handled through signage and expert staff. clear rules like "clean up after yourself, do not hurt yourself or machines, respect the people and culture, do not do anything foolish (e.g., wear safety glasses, keep hair short or pulled back, wear closed-toed shoes)…" (2014, p. 13), ensure that the makers are toeing the line, with penalties being severe and swift; one violation and the violator is out.

The *"Makerspace Playbook"* highlights safety scenarios and how to prevent avoidable accidents. The management should plan for safety, with training on safely operating tools and provision of safety equipment like goggles, earplugs etc.to the makers. The need to create common rules like reporting injuries, using protective gear, preparation, tool usage and cleaning up helps minimise accidents and should be posted around the makerspace. Specific safety guidelines and safety plans should be strictly reinforced to keep makers safe in the makerspace (Michelle *et al.*, 2013).

Makerspace Layouts – There is a general agreement in the scholarly world on what should go into makerspace, however, there is particularly no general layout for what a makerspace should look like. However, concepts like openness, modularity, flexibility and multiple use capabilities have to be considered. Though at its infancy, there is some grey literature that proposes the look and feel of makerspaces. Branwyn (2019) attempts to tackle this in his article "*The Complete Guide to Creating Your Makerspace*", providing an ideal layout for a "home makerspace".

University makerspaces, being multiuse spaces; i.e. learning environments; innovation, ideation, creativity while supporting entrepreneurship, often require them to incorporate educational programs hence prefer layouts that incorporate training rooms, faculty offices, conference rooms in addition to the workshop spaces. The LLC makerspaces layout *(figure 11)* includes five sections: studio; "LLC faculty office; education resources and inventory room; conference rooms; and community space" (Shively, 2017). Yale's *Center for*

Engineering Innovation and Design (CEID), has also incorporated four functional areas: Learning and meeting space, open studio space, controlled shop space and office space (Wilczynski, 2014).

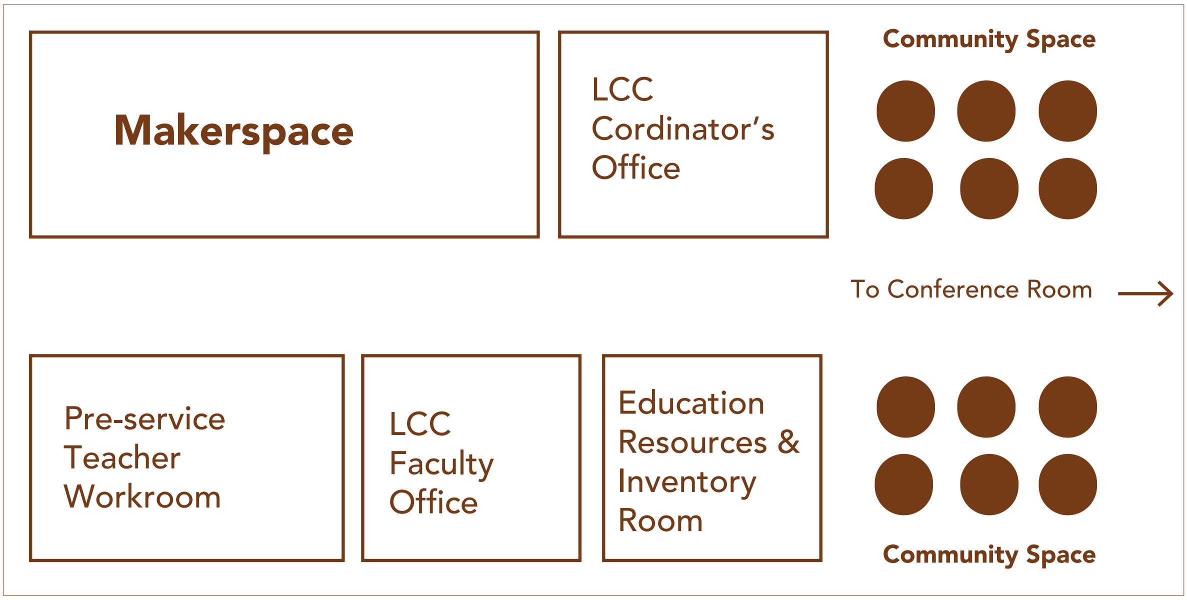

Figure 11: LLC Makerspace Layout (Source: Shiverly, 2017)

In universities that have large student traffic like Georgia Tech's *Invention Studio* (serves 1000 makers per month) the spaces are divided into multiple rooms focusing on functionality;" rapid prototyping, woodworking, plastic working, metalworking, CNC machine tools, mock-up suite, assembly and testing areas, design spaces, and computational design spaces" (Forest *et al.*, 2014).

2.8 Conceptual Framework

A conceptual framework is a "set of idea and principles resulting from relevant fields of enquiry used to structure a subsequent presentation" (Orodho & Kombo, 2005). It is a tool used to help a researcher understand the situation under study (Muragu, 2018, p. 26), providing clarity and keeping the research on track by conceptualizing the problem and linking ideas and data to reveal deeper connections (Orodho & Kombo, 2005, pp. 49–59).

This framework reveals the link between the maker movement and *the maker*. From literature, we observe the need for collaboration, by responding to the *maker* needs, the framework shows how the makers can be centred in academic makerspaces.

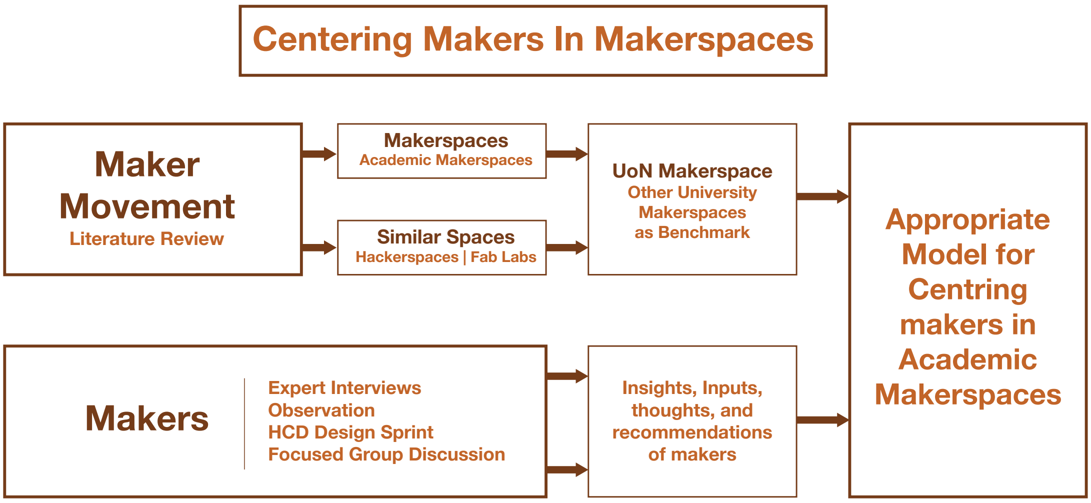

Figure 12: Conceptual Framework (Source: Author)

2.9 Conclusion

This chapter reviewed the maker movement, the makers their role in makerspaces and the making process in makerspaces. There is a dire need to understand the maker and centre them in the making process. The review provided an in-depth understanding of the current situation of makerspaces, how they operate, the makers and their functions.

3 CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Overview

This chapter describes the methodology. A qualitative research method was applied with participant observation, interviews and a focused group discussion with makers.

3.2 Research design

This study was designed to explore and contribute to the novel research on Makerspaces focusing on makers and the making process in the UoN Makerspace. The researcher employed a case-study design method, using the UoN Makerspace as a case for the study. The research was qualitative descriptive research that looked intensively on one "participant" in this case being the UoN Makerspace and activities undertaken at the space, concluding only in the specific context.

Case study research according to Yin, (2017) is a form of qualitative descriptive research that focuses on inquiry of a single or group of participants, concluding specific to that participant or group, in that specific context. The case study research was used by Malaki, (2018) in his study *Co-Design in the Development of effective Museums in Kenya;* targeting three regional museums; Nairobi Museum, Fort Jesus and Kisumu Museums. This research adopted case study research focusing on the UoN Makerspace with an emphasis on exploration and description.

The research also applied exploratory and participatory approaches as research design tools to explore and collect systematic information on the use of makerspaces. According to Burns & Bush (2006) "exploratory research design is gathering information in an informal and unstructured manner". It is used in open-ended contexts where little has been researched on or is understood (Creswell & Creswell, 2017). The role makers play in makerspaces remains vastly unexplored with little information in the academic discourse making exploratory research appropriate for the study.

Participatory research, on the other hand, involves "methods geared towards planning and conducting the research process with those people actions are under study" (Bergold & Thomas, 2012). Muiya, (2018) in his study on *Design Approaches for Community Development* utilized exploratory and participatory research design, focused on methodologies, practice and development by designers. The researcher obtained first-hand information on the UoN makerspace, through participant observation in an HCD design sprint and interviews that were then recorded as detailed field notes and presented via narration.

3.3 Study Area

The study was based at the UoN Makerspace located at the University of Nairobi's College of Agriculture and Veterinary Studies (CAVS), Upper Kabete Campus, Nairobi County. The UON Makerspace is situated next to the Food Science Complex behind the Food Processing Pilot Plant.

3.4 Sampling

There are at least eight makerspaces in Kenya. Including, the Gearbox, Fablab Winam, Fablab Kivuli, Fablab Nairobi, Ousia Fablabs, SwahiliBox Labs and the UoN Makerspace. The UoN Makerspace was selected using convenience sampling. Etikan, Musa, & Alkassim, (2016) define convenience sampling as "a type of non-random sampling where members of the target population that meet certain practical criteria, like accessibility, geographical proximity, availability at a given time, or the willingness to participate are included for the study." The UoN makerspace is operated by the University of Nairobi, hence is accessible to the researcher. The researcher had also been involved in projects at the makerspace making it convenient for the research.

The researcher employed purposive sampling to select the participants for the study. Purposive sampling is the "deliberate choice of a participant due to the qualities the participant possesses" (Etikan *et al.,* 2016). The participants were selected deliberately to provide information by knowledge and experience. Purposive sampling was also used to select the exemplar for the study and the Retro3D Printer for the HCD Sprint. It was selected due to the availability of the original design team, their willingness to try a new process to improve their printer.

3.5 Data Collection Methods and Procedures

The study employed three instruments; interviews, focused group discussions, and participant observation for the research.

3.5.1 Key informant interviews

The researcher carried out in-depth interviews with various key informants whose objective will be to obtain key information. During the interviews, interview guides (see Appendix A), and schedules were used. The key informants interviewed included the Manager of UoN Makerspace, the Makerthon facilitator, the project leads at the makerspace, and a design thinking expert at the facility. The interviews were open-ended and semi-structured to allow for flexibility and customisation of questions while maintaining a level of similarity. The follow-up questions may not have been included in the interview guides shown in (Appendix

B) and were asked out of order to allow the interview to become more conversational to elicit high-quality information and insights.

The interview questions were informed by the research objectives. The questions fall into four themes: Makers, Methods, Tools and Space. Design process questions were designed to obtain information about the making process and ethos used at the UoN makerspace. User engagement questions were geared towards eliciting information on the UoN makerspace makers, the engagement process, the form and level of engagement and the role they play in the maker projects. Finally, Human Centred Design questions were designed to elicit insights on the Human Centred Design approaches being applied at the makerspace, if and when they are applied.

3.5.2 Focused Group Discussion

Focused group discussion (FDG) consisted of a multidisciplinary panel of makers, working at the UoN makerspace, to find out their opinions, beliefs and attitudes concerning the problem statement. They included two incubatees, a student, a postgraduate researcher and the researcher as the moderator. The criteria for selection was that the maker had to have used the UoN makerspace for more than 6 months. All the panellists had experience with the UoN Makerspace and were involved in different projects at the space. The rationale for the selection of the panel was the need to get first-hand information from makers who used the facility daily.

The discussion took the form of an informal discussion with the researcher guiding the conversation. This was meant to elicit information more naturally. The discussion started with an introduction where the researcher gave a summary of what the research was about and requested for permission to sound and video-record the discussion for subsequent transcription and observation. A Nikon D5600 was used to take pictures and record the discussion while a Sony Xperia Z5 voice application was used for audio recording. The discussion lasted for an hour and was later transcribed for data analysis. The data gathered from the FGD consisted of photographs, video recording and voice recording for content analysis.

3.5.3 Observation

The types of observation used for this study were both participant and non-participant observation. Participant observation met the ethnography standards by (Fetterman & Del Rio-Roberts, 2010) which recommend at least six months and immersion into the organisation. The researcher worked on projects and undertook training at the UoN Makerspace for over a year from October 2018 to December 2019. Later, over the course of four months, the researcher made weekly trips to the makerspace, and worked with the Digital Blacksmiths to design 3D printing files, 3D print materials, repair 3D printers and participated in an HCD Design Sprint to redesign the Retr3D printer.

The non-participant observation took the form of visits to the makerspace in which the researcher stayed on the whole day, noted the actions and reactions of undertakings at the makerspace. This involved taking descriptive notes of things happening at the makerspace. Data collection techniques like photography and written descriptions; note-taking and documentation were used. As a novice qualitative researcher, I also used the shadowing technique to collect data.

3.6 Data Collection

3.6.1 Preparation

Data collection began in October 2019 and lasted until March 2020, a six-month window. However, exploratory research proceeding the data collection phase began in October 2018, with training on 3D printing and CAM/CAD at the facility. This exploratory phase included taking design classes on Solidworks three days a week for three months under the supervision of a trainer at the makerspace. The researcher also attended hackathons and I2M (Idea to Market) events that took place at the makerspace meeting participants.

The next phase of the training from May 2019 to September 2019, the researcher was attached to Digital Blacksmiths, a UoN Makerspace incubatee that specialises in 3D printing to learn the practical aspect of 3D printing. The researcher designed 3D designs for printing using Solidworks software, under the tutelage of the Digital Blacksmiths Project manager and the designs were then sliced using Repetier-Host a 3D printing software, before printing them using the Retr3D printer. I also took part in the Retr3D printer repairs and troubleshooting, interacted with clients, makerspace users and did 3D printing as part of his everyday activities.

3.6.2 Implementation

First, the researcher contacted the potential interviewees in person to book an appointment and gain consent to interview them. All the key informants except one accepted to interviewed, there no response from the director, Gearbox despite repeated emails to request for an interview. The requested interviews were between 30 and 45 minutes at a time and location most convenient for the participants, though some interviews took longer than that. The interview with a Human Centred Design expert from C4D was ad hoc due to the availability of the interviewee. The interview took place on the side-lines of the Makerthon. All the interviews were conducted at the UoN Makerspaces on the dates shown in *Table 1* below

Interviewee	**Date**	**Source**	**Format**	**Length**
Project Lead – UoN Makerspace	29.10.2019	Purposive sample	Semi-structured interview	30 min
Manager – UoN Makerspace	1.11.2019	Purposive sample	Semi-structured interview	42 min
CTO – Fedha Electronics	29.10.2019	Referral by Project lead	Semi-structured interview	40 min
Makerthon Facilitator – UoN Makerspace	29.10.2019	Purposive sample	Semi-structured interview	1 hr
Design thinking Expert – C4D Lab	2.11.2019	Referral by Makerthon Facilitator	Contextual interview	40 min
UoN Makerspace Users (5)	10.02.2020	Convenience Sample	Focused Group Discussion	1 hour

Table 1: Interviews (Source: Author)

At the beginning of an interview, each participant was informed of the purpose of the study and the use of their recorded voice. The interviews were in person, the researcher used an interview guide that listed potential questions, but additional questions and follow-up questions were included to get clearer answers. During the interview, the researcher rearranged, omitted and asked follow-up questions as appropriate. To aid memory recall the researcher used the native sound recording application of the Sony Xperia Z5. The selected interview location was at the UoN makerspace, with minimum disruption. After the interview, the researcher thanked the participants and asked if they had any questions. The voice recordings were transcribed to prepare them for content analysis. All the interviews were individual interviews except one that took the form of a focused group discussion. The FDG had five participants comprised of makers; two incubatees, a student, a postgraduate researcher and the researcher as the moderator. All the interviews were conducted in a span of three months.

Participant observation was performed of a span of two months to observe the makers, their making and engagement process at the makerspace. It also took the form of an HCD sprint, the researcher conducted a workshop to redesign the Retr3D printer. The researcher was allowed to take field notes and photographs for subsequent analysis. Non-participant observation occurred on many occasions while the researcher worked on various projects at the UoN Makerspace. This was done not to interfere with the participants' work. For instance, the researcher attended the Makerthon as an observer taking field notes and pictures to provide material for analysis.

3.7 Content analysis

Data analysis is performed in chapter 4. Data analysis was based on visual on thematic analysis. Data was presented in narrative forms focusing on descriptive and content analysis. Content Analysis is used to analyse written documents; transcribed interviews, conversations, articles, reports and notes systematically and objectively (Välimäki, 2018).

Data Preparation: All the interviews and discussions during the Design Sprint were transcribed. The sticky notes and remarks from the exercise were grouped and classified for the analysis.

Categorisation: The research data was classified into four themes: Makers, Methods, Tools and Space. I also relied on my experience in the field to classify answers from the interviews and observations.

3.8 Logical Framework

Research Question	Objective	Data needs	Data source	Method	Output
1. Who is a maker and how do they engage within an academic makerspace?	To map out the makers and the engagement process in academic makerspaces.	Key stakeholders Engagement process	Leadership Makerspace Participants Project leaders and managers	Observation Forms and checklists FDG Photography	Stakeholder map and User journey of the UoN makerspace
2. What is the typical making process at the UoN Makerspace?	To articulate the making process at the UoN makerspace using a human-centred design approach	The design process	Management Makers & project managers HCD Design Sprint	Observation Forms and checklists FDG Photography	Making process
3. What engagement model would be appropriate for makers in Academic makerspaces?	To propose an approach that to be incorporated into projects in makerspaces	Model design	Design thinking Experts	Interview of key internal makers and HCD Experts Desktop research	Proposed engagement model for makerspaces

Table 2: Logical Framework. (Source: Author)

3.9 Conclusion

The research methods and techniques used by the researcher during the study are highlighted. The researcher employed a case study design of the UoN makerspace, with the research taking an exploratory and participatory approach. The tools used included interviews, focused group discussions, and observation. Convenience sampling was used to select the case study while purposive sampling was used for selecting the participants.

4 CHAPTER FOUR
DATA ANALYSIS, PRESENTATION AND INTERPRETATION

4.1 Overview

In this section of the study, an examination and explanation of the findings of the research are done. The data collected through participant observation, semi-structured interviews, document analysis, focused group discussion and photographs were analysed qualitatively.

4.2 Presentation of Findings

4.2.1 Background Information

Figure 13: The UoN Makerspace (Source: UoN Makerspace)

The UoN makerspace was started in 2009, by Dr Kamau Gachigi, who was then, the director of the University of Nairobi's Science and Technology Park (STP). STP is mandated to accelerate and incubate innovations developed across the university to prepare them for commercialization. The Makerspace was born out of the need to provide an avenue for light manufacturing, prototyping, innovation and incubation (Gachigi, 2015). What started as Fablab Nairobi, grew into the UoN Makerspace intending to offer students at the university a hands-on approach to creation and an out-of-class interaction with tools used in the industry.

The UoN makerspace, initially located at the school of Engineering's mechanical engineering department, was moved to CAVS, Upper Kabete Campus, due to the increased demand for more space to house more machinery and equipment. The makerspace has one Laser cutter, one CNC milling machine, 13 3D printers and one Vinyl cutter for prototyping (Mugasia, 2018).

The makerspace gives, innovators, tinkerers, artists and makers access to tools and resources to create the products through experimentation and exploration making using digital tools. It also offers an environment designed to boost creativity and problem solving helping accelerate the transformation of their projects. They also offer room to incubate start-ups; Digital blacksmiths and KrisKrafts were incubated at the makerspace during the study.

4.2.2 Research Data

This research combined literature review, secondary data and primary data using methods by Yin (Yin, 2017, p. 153). Data was gathered through participant observation; HCD design sprint, interviews with experts and FDG with UoN makerspace users.

Qualitative data for this research was gathered in two parts; the data gathered in the 3D Printer design sprint with experts and data from interviews with the UoN Makerspace Makers. Multiple research instruments and methods for gathering and analysing data were applied. The HCD Design Sprint consisted of the following sessions: understand; diverge and converge;

Conceptualizing and Prototyping and the final session on Testing, conducted in a span of four days. The types of data gathering used in the design sprint are presented in the table below and explained below.

Instruments	**Team formation**	**Understand**	**Diverge & Converge**	**Prototyping**	**Testing & Documentation**
Photographs		✓	✓	✓	✓
Video Recordings		✓			
Note-taking		✓			✓
Flipcharts		✓	✓		
Observation	✓	✓	✓	✓	✓
Sketches		✓	✓	✓	
Computer tools			✓	✓	✓
Methods		*Content Analysis*	*Content Analysis*		

Table 3: The HCD Design Sprint Data (Source: Author)

The data gathered from the understand phase through to the testing phase consisted of photo documentation of the whiteboards and flipcharts, documented during and at the end of each exercise. A total of three hundred photographs were collected during the sprint. The whiteboards and the flipcharts included text, sticky notes, sketches and titles. The initial sessions were video recorded for insights to ensure the correct interpretation of the contents in photographs. The team, however, agreed not to record all the sessions as written information was considered sufficient. The observation was done using notebooks that were provided at the beginning of the design sprint.

4.3 Interviews and Design Sprint

The research was conducted to understand more about academic makerspaces and makers. Five experts interested or working at the UoN Makerspace were interviewed to understand the relevant stakeholders and making processes involved in the makerspaces. Each interview lasted between 30 minutes to 1 hour. The specialization of the interviewees included; the UoN Makerspace Manager, the Project Lead, a Design thinking expert, a Makerthon Facilitator, and a makerspace enthusiast.

An HCD Design Sprint was organised with makers at the UoN Makerspace to understand more about the making process. The Participants included one electrical engineer, one mechanical engineer, one product designer, one communication expert, a Human Centred Design expert and the researcher who was also the facilitator.

4.4 Results

The interview results include quotations analysed from transcripts of five interviews. The results are discussed in four main categories; 1) Makers and Engagement Process 2) Making Process, 3) Location and Space, and 4) Tools and Materials.

The first category focuses on the first research question (Makers and engagement process), while category two responds to the second research question (Making process), using an HCD design sprint. The last two categories respond to the third research question (an appropriate model for makers). Under makers and engagement; user involvement, management and collaboration were the key elements that came out. under the making process, the Human Centred Design process was highlighted. The last category looks at valuable reflections from participants on space, safety, tools and training at the UoN Makerspace.

4.4.1 Makers and Engagement Process

Makers are the key stakeholders in a makerspace. From the literature review, makers are individuals who utilise a makerspace to build and create. In general, these are the people who use the UoN makerspace for their day to day activities. At the UoN makerspace, they were involved in different projects, either individually or as part of a larger group. The following are makers that were involved in projects at the UoN Makerspace during the study.

4.4.1.1 Makers

The UoN makerspace is an open space that is accessible to a variety of users; partners, donors, corporates, start-ups, UoN management, staff, innovators/enthusiasts, students, interns and start-ups.

Figure 14: UoN Makerspace Makers (Source: Author)

Partners

Although partners were not directly involved in the day to day making process, they play a very important role in funding projects, by providing resources, they allow makers to create solutions. The UoN Makerspace has partnered with some organizations for different projects. The Lead engineer noted; The partners fund the programs and projects and, in some projects, they determine which projects can be undertaken. The MNCH project "… was a focus that some partners (concern worldwide) had. They were focusing on maternal health…."

During the study, the partners involved in funding projects at the UoN Makerspace included Concern Worldwide and Philips Foundation who were involved in the Making for Maternal and Child Health projects; UNICEF; the partner for an air sensors project (Open-Seneca); The Centre of Global Equity was involved with the Makerthon. The UoN makerspace had also partnered with organisations to implement the solutions resulting out of the makerspace; the Kenyatta National Hospital was the implementing partner for the MNCH project.

How does the makerspace get partnerships with donors or new partnerships? The UoN makerspace manager noted they acquire partnerships through applications and targeted proposals. Once the partners' come-on board they sign an MOU, with the university, showing that they are offering a grant to the University via the UoN Makerspace to conduct a certain project. The application has to be submitted with the University's legal office for processing before a partner or donor can work with the UoN makerspace.

Staff

The staff at the UoN Makerspace, are persons hired to work at the makerspace. The UoN makerspace had a permanent staff of six, with ten student volunteers. The makerspace had a UoN makerspace director; who was also a member of faculty, a makerspace manager, a lead engineer, a project manager and a communication lead. The staff also double up as the training instructors, although experts were called in from time to time. Students volunteer at the space when there are maker events like a hackathon or I2M training. There was one subordinate staff who did cleaning at the makerspace during the study.

The staff at the UoN Makerspace maintain the makerspace operations, repairing the machines, ensuring cleanliness and training the users. They work with the equipment daily, offering assistance to the makers when required. The researcher noted all the staff members, bar one; the cleaner had a background in engineering.

Students

At the UoN makerspace, the students make up the majority of the makers at the space. The Makerspace manager explained this is because space is "their facility" considering that the makerspace was started to offer students experiential learning. Students from the University of Nairobi have access to the makerspace from Monday to Friday to create their products.

During the study, the researcher noticed that the majority of students were from the school of engineering. The UoN makerspace manager noted; “We do have a few creative artsy type people in the space, but it is that most of the uses that we know the machines can be used for are engineering-based uses. We haven't had people who have concentrated on the art-bit of using them.”

The manager, however, explained that during projects students from all schools are invited. This was evident from the Makerthon poster (see figure 15 below). Students from other universities and colleges are also allowed to use the facility, after approval. During recent Makerthon, students from several local universities (Kenyatta University, University of Nairobi, Moi University, Jomo Kenyatta University of Agriculture and Technology, Multimedia University, Technical University of Kenya, and the University of Embu) regardless of which course you are taking signed up. There were also international students from Utrecht University (Netherlands) and Katholieke Universiteit Leuven (Belgium), during the study.

Lack of students from other departments at the University was blamed on unhealthy competition and secrecy between departments in the university. The lead engineer opined that because of the way departments have done their research, collaboration is still a new concept across the university.*"It is still a little difficult for institutions to do that because traditionally each department has done its own thing and they have taken all the credit for it..."*

The location of the UoN Makerspace, at Upper Kabete, far from other colleges has also contributed to lack of multidisciplinary teams at the space. Due to its location, most students, find it difficult to access the facility, despite the provision of "Free" transport services by the University.*"...you may not see guys from the school of design here because physically the place is located away from where they are and it takes an extra effort for someone to say."* Makerspace Lead Engineer. The manager recommended the need for awareness, on the offerings of the UoN Makerspace, to inform students on what the space offers; the tools, training, opportunities and the collaborative aspect of the space.

Innovators and Enthusiasts

The UoN makerspace is open to innovators and creation enthusiasts who are not part of the university community at a fee. They have access to the facility and the machines for prototyping and creation. The manager emphasised that stating *"…it is open for anyone as well…as well as individual innovators who just want to use the machines."* During the research only one enthusiast; Nicholas Kimali, the founder and CEO of Fedha Electrics Limited. Kimali is an award-winning embedded system engineer with interests in embedded systems microcomputer applications and industrial systems. During the study, he was working on an improved speed governor.

Innovators have access to tools and resources at the space, at a fee and sometimes take up training roles to new makers usually students. *"... I train my team as we go along. They learn as we are working, they can design."* Kimali.

Interns

The UON makerspace also takes in students on internships to help them gain experience. Interns have access to the makerspace, where they undergo training on how to use different tools, machines and software. They are trained on different design approaches including design thinking and work alongside seasoned makers. The interns pay a fixed fee of about Ksh. 3000, to use tools and resources for training purposes. They are then paired with seasoned makers over a period of 3 months. The interns are usually students from engineering faculties looking to learn about engineering design, machining, and manufacturing.

The interns are exposed to different spheres at the facility. The researcher was tasked to take interns through an empathy mapping exercise with two interns, during the study. We visited the agriculture farm of the University of Nairobi's CAVS where we interviewed staff and students from different agricultural departments to identify their needs for a future project.

Researchers

The researcher was one of the two researchers who were using the facility as the case study for their studies during the period of this research. The manager said they have postgraduate students from across the globe interested in researching the space from time to time. Besides, the researcher, there was a PhD student from Katholieke Uni-Leuven, Belgium undertaking anthropology.

Start-ups

The facility offers space to start-ups seeking to accelerate and structure the process of creating successful businesses by providing them with full support; incubation space, training, financial support, technology and professional support services, and networking opportunities. The aim of opening up the Makerspace for start-ups is in line with the mandate of the Science and Technology Park, of accelerating and incubating innovation across the university for commercialization (Mugasia, 2018). The incubatees have access to space, power, machines and storage.

During the study, two start-ups were incubated at the UoN makerspace; Digital blacksmith and Kris Krafts. Digital Blacksmiths are a network of entrepreneurs and makers developing social impact products in the developing world (Menke, 2016). The network aims to build social businesses with start-ups and are already working in Kenya, Ghana and Tanzania. The Digital Blacksmiths have so far produced a Retr3D printer, a digital Microscope and ethical 3D printer filament made from recycled plastic waste (Norris, 2017). At the UoN makerspace, they have access to space, network and tools to create their products. They offer 3D printing services to makers at the makerspace and maintain 10 3D printers that are available to other makers while training the makers on 3D printing. The researcher was attached to the Digital Blacksmiths during the study.

Kris Krafts is a start-up making artsy accessories by taking everyday materials, such as wood, plastic, leather, fabric and paper to make artistic products. The start-up is owned and run by a sole proprietor, maintaining an online shop for orders, with no physical retail space but rather focus on deliveries. They create custom-made items using a laser cutter to cut and raster wood, plastic or leather. At the UoN makerspace, they have access to the required tools at an annual fee. The KrisKraft proprietor noted that "I pay a yearly fee that is very subsidised, a percentage (5%) of yearly revenue.". In addition to the owner, the start-up had one employee who did the day-to-day chores.

The makers noted that the makerspace has a lot of potentials and should seek to attract start-ups with packages, considering the need for space, availability of tools and training for new companies

Corporates

In the aim of being financially sustainable, the UoN makerspace has started a program to offer services to companies and clients. This is done by offering tools and resources to interested companies to prototype at a fee. A company approaches the makerspace to developed a solution for them, normally a product. The team then designs and delivers the product at cost. During the study, however, there were no corporates at the UoN makerspace. The manager of the makerspace, however, noted that companies from time to time, approach the makerspace to solve innovation problems for them.

4.4.1.2 The Engagement Process

At the UoN Makerspace, the engagement process starts from the point when potential makers learn about the makerspace. The makerspace conducts periodical awareness exercises and participate in events, training and activities across the university. Recently participated in the Nairobi Design Week and conducted a 3D Printing Workshop at the School of Arts and Design.

Although the Makerspace management conducts sensitization activities, from the focused group discussion with makers, most makers at the makerspace were introduced to the UoN Makerspace by their friends who were already working at the space. *"I just showed up one day, and I met people… In 2016, I was on a work break and I came here with my friends, and they were working on some engineering products…"* (FGD-B)

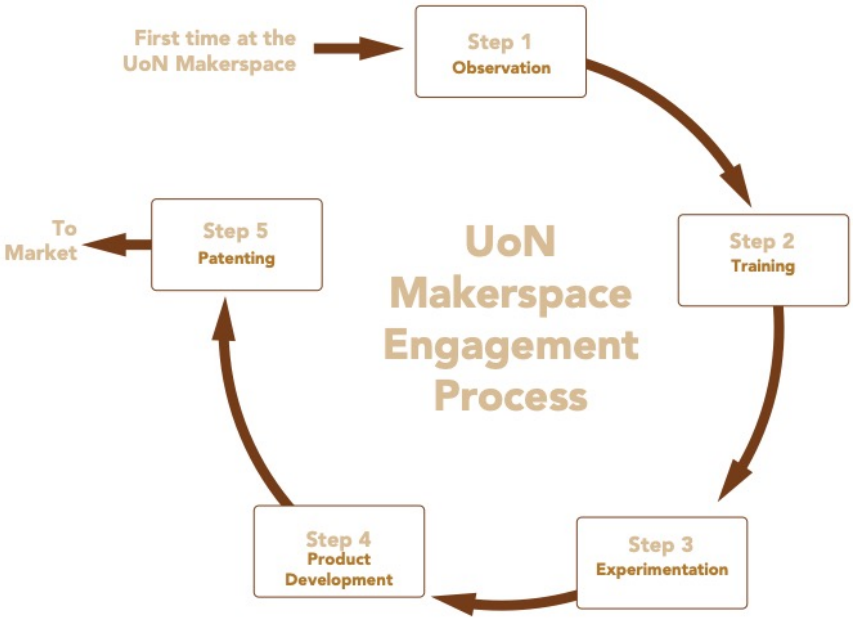

Figure 15: Engagement Process (Source: Author)

Observation: When the potential makers arrive at the makerspace the first time, they observe what the other makers are doing. They watch how they are using the machines, tools and materials. This often happens in the first week. It arouses their curiosity and helps them identify the tools and products that they want to work on. They interact with seasoned makers and understand how the facility works. One maker in the focused group discussion said: *"The first thing you do is observe what people are doing, you just kind of stick around people, who are* *doing something that you are interested in."* (FGD -B) "*I used to come and sit and watch Solomon work with a 3D printer, and then I'll start asking questions. How do you make this?"*

Training: After the initial week, the potential makers are taken through a thorough training exercise on how to use the machines and tools in their area of interest. The researcher was paired with a 3D design expert, to work on Solidworks, to learn how to design for 3D Printing for a month. The same trend came out during the FGD, where the participants said: *"I didn't know how to operate the machines, the engineers taught me how to do it."* (FGD-B)

Product Development: Makers at the space are encouraged to create solutions, either by joining teams that are working on innovative solutions or by collaborating with other makers to come up with new products. Working alongside other makers helps the product development process move faster and can help you get a new idea, as noted by one maker "I might get stuck and the solution may be very easy… People come in with different ideas, different things that need to be done, and so that is why I come to the makerspace" (FGD - A). The researcher looks at the making process at the UoN Makerspace in depth in the subsequent subtopic.

Patenting: Once a maker or a group of makers come up with an innovative product, the management at the makerspace helps them patent their solutions before they are commercialised. This helps safeguard their Intellectual Property rights. The UoN makerspace and university, in general, does not lay claim to the property rights of the solutions coming out of the makerspace. The makers own the full rights of their solutions and can commercialise them. The university through the patenting office, helps makers patent their products for a fee of Ksh. 7000, that is subsided for makers working out of the UoN Makerspace.

The makerspace works under the principle of collaboration and networking, with members being encouraged to share and help one another working in the space. This was echoed by a student maker as the reason why he comes to the makerspace: *"Why I come to the makerspace is collaboration and building my networks."* (FGD-C)

4.4.2 Making Process

The researcher had the opportunity to observe and participate in a making exercise at the makerspace. The purpose of the exercise was to observe the process used to make products at the makerspace. The researcher observed that making process at the makerspace, was predominantly the Engineering process, although they made use of the Human Centred Design process from time to time. The Makerspace Manager explained that this is because: *"most of the projects that we are working on currently are engineering-oriented the thing being that the projects are engineering-oriented in one way or the other."*

4.4.2.1 The Typical Design Process

The engineering process is the widely used making process at the UoN Makerspace. It involves a series of steps that are used by engineers for product development. The making process at the UoN makerspace starts with receipt of a brief (often open-ended from donors). Design teams identify the design needs and constraints. Then, they conduct problem research to develop potential solutions. The solution with the greatest potential is then selected for prototyping, testing and evaluation. Finally, the team improves the product as needed (Cooper, Zarske, & Carlson, 2008).

Figure 16: Engineering Design Process (Source: Adapted from Khandani, 2005, p. 11)

The end product - user in this process is only involved at the testing stage. The users were brought in to provide feedback. In some cases, they were not involved entirely. The researcher also noted that the teams working on maker projects were entirely made up of engineers. When asked it, the manager about noted that *"most of the projects that we are working on currently are engineering-oriented.*"

4.4.2.2 Human-Centred Design at UoN Makerspace

The researcher noted that makers at the UoN Makerspace, made use of design thinking (HCD) in training projects and projects when the donors have requested for the process to be used. During the study, the researcher participated in a Makerthon, an HCD training exercise that takes place quarterly at the Makerspace. The UoN makerspace in collaboration with the Centre for Global Equality from the University of Cambridge conducted an 8-week hands-on learning-by-doing program to innovate towards reducing maternal and child mortality. The exercise was meant to train researchers from the Centre for Global Equality to equip them with skills to set up and run a hackathon in Bahir Dar Institute of Technology (BiT), Ethiopia.

A Makerthon (also called hackathon), is an event of any duration where people gather to solve problems (Tauberer, 2014). It is an event that is organised to give up-and-coming innovators an avenue to build, create and showcase their innovations based on a given theme provided by the organizers (JKUAT & UN-Habitat, 2019). The exercise took eight weeks, with weekly workshops taking place on Saturdays. The third workshop took place on a Friday, due to the visit to Kenyatta National Hospital.

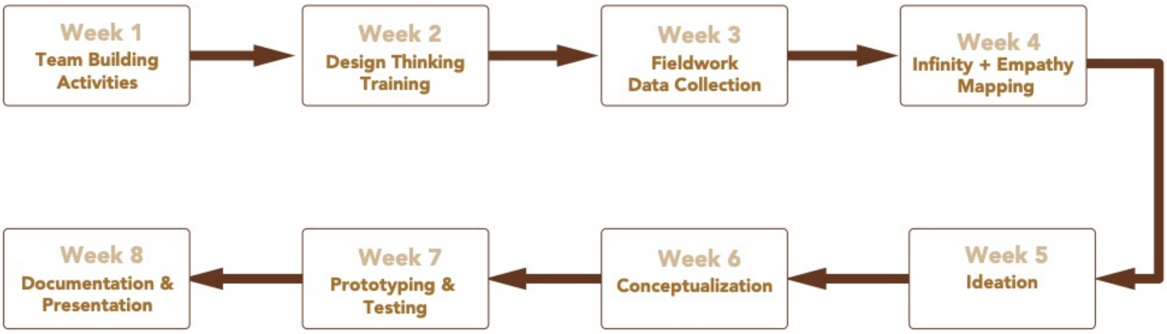

Figure 17: Typical HCD process at the UoN Makerspace (Source: Author)

Team formation

The Call to all students regardless of which course you are taking. Sign-ups of students from Kenyatta University, University of Nairobi, Moi University, Jomo Kenyatta University of Agriculture and Technology, Multimedia University, Technical University of Kenya, University of Embu, TU Delft, Netherlands and a PhD student from Katholieke Uni- Leuven, Belgium doing anthropology. This was done to encourage the cross-breeding of ideas. The same way an engineer thinks is not the same way an anthropologist/ business/ medical student will think. For an engineer it will be technical, anthropologists will think about the person, the doctor will be emphatic to the patient, a business person will bring a model of business; can this sell?

Four teams were selected and groups of 6-7 individuals formed, incorporating students from different disciplines. Every group had a facilitator from the UoN Makerspace, who assisted the project manager in guiding the other participants. The teams also had a chairperson, a secretary and a timekeeper.

Before the Makerthon the internal makerspace team had a brainstorming involving everybody on how the Makerthon should look like. They mapped out in co-relation with previous hackathons.

Day 1: The first session involved team building, team dynamics, what to expect among team members. Activities to ensure that the team gels. By the end of the day, the atmosphere was bright, with participants not wanting to leave with the excitement very high.

Day 2: The second session, dived into design thinking. The participants were taught about design thinking, its stages and what it entails by Dr Samuel Ruhiu from UoN School of Computing and Informatics. The participants were trained on empathy and prepped for fieldwork. How they were going to involve the user, how to put the user in their design. They were also taught data collection techniques, how to conduct interviews, how to record data, taking photos and audio-visuals.

Day 3: The third workshop was on a Friday, involved fieldwork at Kenyatta National Hospital (KNH). All the logistics had been organised prior. The participants met at KNH (Biomed meeting room). They were prepped on what to do, how to handle themselves, asking for consent (not to record or take pictures without permission). The participants were divided into two groups; one group went to the new-born unit while the other group went to the labour ward. Each group had one hour to conduct the exercise at each section before switching or shifting to the other. The participants went to both sections to observe and conduct interviews so that they could get insights that they could innovate on. Each group was taken across by a nurse and a BioMed so that they are told all the processes, take notes, observe and ask questions. After the morning exercise, the participants had refreshments, before going back to the BioMed room. Here they went back to their groups and recorded what they saw. At this point there was no discussion, just saying and noting down what they noticed in raw form. After that, every group presented their findings to the whole gathering. Other participants were encouraged to add to what they had missed.

Day 4: This session involved infinity maps. Each group members put their information on sticky notes and posted them on the boards. They then grouped and themed the sticky notes. They grouped information into themes to make sense of the data. At this point, the participants started analysing the data. After that, they moved to empathy mapping trying to gauge how the users felt. For instance, at the labour ward, one lady said "do they have any sanitizer now? Thank God!" when she was asked if the hand sanitiser contained sanitiser. These kinds of insights helped the participants know the current situation. These were used to create a point of view (POV) from observations.

The participants then proceeded to How Might We Questions (HMW). They generated questions from key insights without answering any questions. At this point, they were not looking for solutions.

Day 5: This workshop focused on ideation. At the initial ideation stage, discussion among group members was discouraged. The participants were advised to generate as many ideas as possible. The project lead advised the participants to go for crazy ideas. The judgement of ideas was not allowed, the more the ideas, the better. The participants were told to avoid thinking logically. Anything that they could think of was encouraged, participants jotted down ideas on sticky notes and posted them on a whiteboard.

The next phase involved refining the ideas, the groups presented before the whole workshop, getting input from other members. The groups then narrowed down to doable ideas. Ideas were constrained to time, cost and availability of materials.

Day 6: The morning session involved participants meeting in their groups to discuss their solutions. They then presented before the class, on where they had reached. This involved their entire process, empathy mapping, point of view, HWM questions to their proposed solution. The other groups asked questions, comments and add-ons. They were taught on presentation and communication skills. Every group was supposed to narrow to one solution but some groups still had two or three ideas and could not agree on one. The project lead used the butterfly technique to select the ideas that created a buzz among participants from other groups. He eliminated the choice of the idea from the group members by having members from other members to vote by adding sticky notes on projects that they liked. This ensured that the groups with attachments on projects worked on popular projects. One group had the project that they wanted to do getting the least votes, whereas the selected one solved all their HMW questions.

The evening session involved a lecture on conceptualization to implement their solutions. They were taught how to do a bill of materials (BoM) for prototyping. The following week involved designing their concepts using Solidworks reading them for prototyping.

Day 7: The seventh workshop was centred on Prototyping and Testing. The groups used the morning session to prepare and realign their Bill of materials and design concepts for presentation. They translated their designs into CAD designs using Solidworks and prepared a list of the materials and tools they need for their prototype. After the morning session, there was a presentation from Ernest Kimani; a resident Mechanical engineer at UoN makerspace, on the conceptualization process. The participants were taken through the modalities of conceptualization, and its intended outcome. They then went back to their groups and finished on their prototypes. During the group work, the researcher moved from one group to another, asking questions and taking photographs on the groups progress.

The afternoon session started with a group activity before the actual presentation. The actual presentation made use of the Pecha Kucha format; with each group getting 15 minutes to present their concept, explain their solution and the bill of materials need to actualize it. During the presentation, the facilitators asked questions to the presenting groups seeking further explanations. After the presentations, the teams were given feedback to incorporate on their BoM and designs for the following week's workshop.

Day 8: The final workshop entailed presentations of final solutions before judges. The teams, presented their final solutions, before a team of four judges. The team leaders presented their medium-resolution prototypes, explaining how they worked. They also describe the creation process, with images projected on a projector showing the entire process. The audience (other participants) fielded questions that were answered by the presenting group. The members received feedback from the seasoned judges that, they promised to incorporate in their solutions.

The judges were impressed with the postpartum haemorrhage (PPH) Kit, that was simple and easy to use. The end-product allowed the health workers to access all the tools in one device, hence can be used to prevent PPH bleeding.

Although the management is aware of the benefits of HCD to the making process, they seldom use it because they consider it very long; taking 7-8 weeks to create a solution. To address this the researcher, proposed an HCD design sprint, that is shorter and more inclusive.

4.4.2.3 HCD Design Sprint

An HCD design sprint to redesign the Retr3D printer, by Digital blacksmiths was selected purposively. A design sprint is a five-day process for problem-solving through design, prototyping, and testing ideas with customers to create solutions quickly (Knapp et al., 2016). A design sprint is a lean approach used to create solutions quickly without building and launching the final product. It utilizes six problem-solving ways to tackle design challenges; Understand (Day 1), Diverge (Day 2), Decide/Converge (Day 3), Prototype (Day 4) and Validate (Day 5). The sprint helps teams to solve problems quickly, allows early and cheap failure and allows for collaboration. The researcher settled on a design sprint due to time constraints and a limited budget. The participants were contacted two weeks before the design sprint, to confirm their availability to join the design team. However, assembling a team of experts for the full five days of the design sprint is costly and difficult hence we settled on a compressed 4-day version with all the key phases as defined by (Knapp et al., 2016); *Understand, diverge, converge, prototype* and *test.* The design sprint was conducted in 4 days (Monday, Tuesday, Thursday and Friday).

Team formation

The researcher, selected six participants for the design sprint, comprising experts to form a multidisciplinary group. The different disciplines required in product development were represented. The team included one electrical engineer, one mechanical engineer, one product designer, one communication expert, an HCD expert and the researcher who was also the facilitator. Half of the participants had over three years' experience in their disciplines, two had no experience with HCD, but were experienced in the engineering design process. Three of the participants were users of the current 3D printer, two had a basic knowledge of 3D printing while one had not interacted with a 3D printer before.

The participants were deemed satisfactory for the study. The group was dominantly male, (four males, two female) which may or may not impact the results.

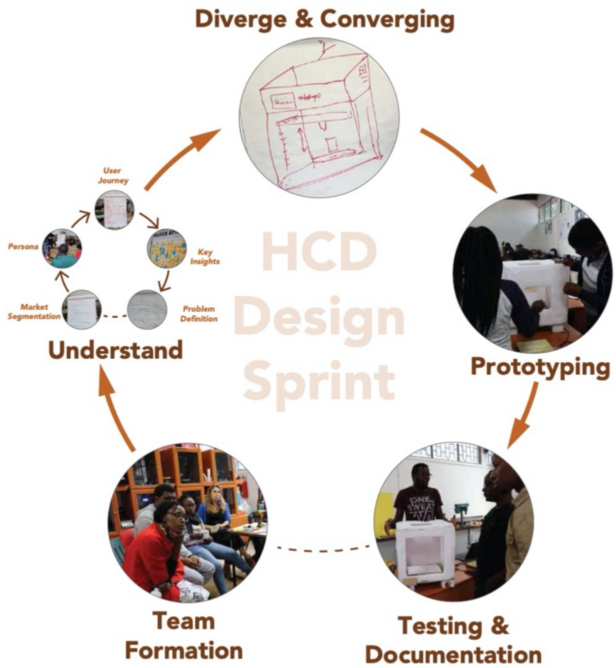

Figure 18: Structure of the HCD Design Sprint (Source: Author)

Understand

The researcher opted for a semi-formal workshop to enhance creativity. This claim is supported, by a study by Vohs, Redden, & Rahinel (2013) that found out that being in "a messy, disorderly room would stimulate more creative ideas than sitting in a tidy, orderly room." Creativity is enhanced by getting away from tradition or the norm. A disorderly environment helps people do just that while orderly environments, in contrast, encourage convention and playing it safe.

The design sprint started with a short introduction explaining the Human Centred Design process, the terminology, the team members, their roles and the goals of the exercise. The researcher took the role of the lead facilitator with a more observatory role as opposed to a more direct role of intervening. He was assisted by the HCD expert to facilitate the sprint.

The team assembled at the Digital Blacksmiths corner (at the UoN Makerspace), all the members sat around a table, with notebooks, marker pens, sticky notes, pencils and pens. The current 3D printer was placed at the centre of the table. The facilitator stood at the front with a flipchart. The design sprint was open to the other members of the UoN Makerspace with walk-ins encouraged. The participants thought it prudent that new participants would add a new perspective to the design exercise. Over the period of the sprint, 15 different UoN Makerspace users participated in the design sprint.

The facilitator-led the team through the stakeholder mapping exercise. The participants listed all the potential users of the 3D printer. The team settled on 3D Printing Enthusiasts as the most viable market using the following factors; a) The size of the market, b) Ease of doing business, c) Length of time to convince them to buy a 3D printer, d) The willingness to purchase a 3D printer and e) 3D printing awareness.

The team then created a persona of a "3D printing enthusiast", his needs, what he does, where he works, where he lives, when he uses a 3D printer, how often he uses it and what he uses it for. The team then created a user journey of a typical 3D printer user. They mapped his day, from when he decides to get a 3D printer, unboxing it, conducting the first print and returning it to the retailer if it fails.

The team made use of an empathy map to deeply understand the person we were designing for. The information was unpacked in a quadrant (Say, Do, Feel and Pains) layout on a whiteboard.

The facilitator then using sticky notes, populated the whiteboard taking note of the users' traits. The participants paid careful attention to the user's clues to infer pains and feelings. This helped the team to identify the needs to define the design challenge. They used the key insights that could be leveraged on to respond to the design challenge. Using sticky notes, the participants individually wrote and post insights that they identified on the whiteboard.

The team then grouped all the insights under key thematic areas; Aesthetics, Accessible design, Services, Operations and User-friendliness. They then sorted them to remove insights that were ambiguous or that had been repeated. The insights were then used to come up with How Might We (HMW) questions for the next stage.

Diverge and Converge

Day two started at around 10 am, with a recap session. The researcher took the team through a quick recap of the previous session. The team was joined with new participants, working on different projects at the UoN makerspace. A social Anthropologist, an agriculturalist and a textile designer joined the team for day two. This was as a result of the buzz that the design sprint had the previous day.

The brainstorming questions were based on HMW questions from the previous session. The facilitator started with one HMW question, he wrote it on the whiteboard. The participants were encouraged to write their ideas, on sticky notes, individually and post them on the whiteboard. There was no discussion during this session, though building on ideas of others was allowed. The facilitator encouraged "wild Ideas", and judgement was deferred for later. The ideas were posted under each HMW questions. The session took approximately 30 minutes.

After the brainstorming session, the team selected two ideas to develop further. The ideas were filtered to remove repeated ideas and merge those that were close or could be implemented together. Ideas that were costly and inapplicable were also filtered out. The criteria for selection included the cost of implementation, applicability, and how interesting they sounded. We group them under sure bet, interesting and longshot. To narrow down on the ideas the team was forced to vote when we could not agree on an idea. Using sticky notes the participants marked ideas that they were attracted to.

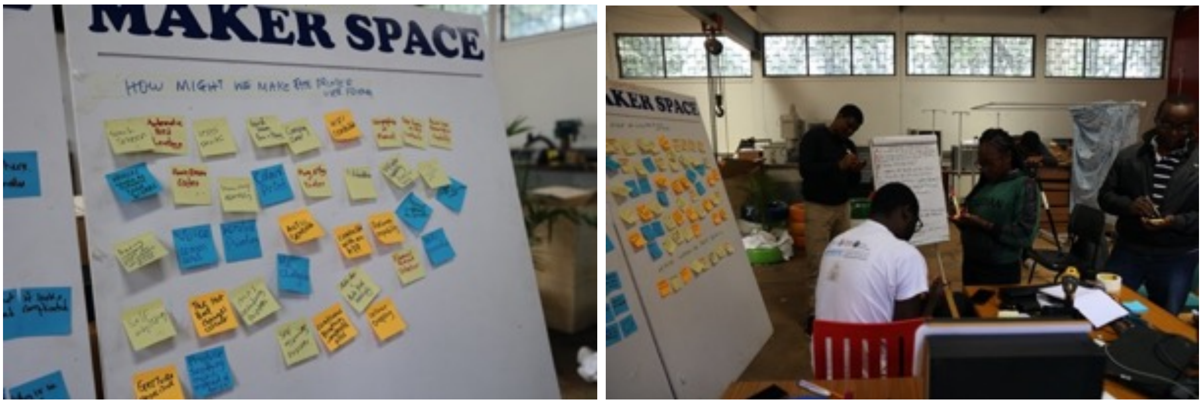

Figure 19: Brainstorming Session (Source: Author)

The session was concluded with a collective statement of what our 3D printer should have. "A 3D printer that has a colour display touch screen, resume capability, can auto-level and auto-stop sending error messages, has a 64-bit motherboard, has proper wire management, a high precision lead screw, better stepper motors, clear hazard signs using icons and the bed changes colour when hot, with an aluminium casing"

Prototyping

The participants were encouraged to conduct a quick in-depth research on 3D printers that were in the market and sketch their ideas for the following session the next day. On Friday, the team started by sketching their ideas on a flipchart. Each member sketched their ideas on the chart. The emphasis was on the structure as opposed to a fine sketch.

The team debated on the sketches and incorporated the ideas to create one design for the prototyping session. They agreed to start with a low fidelity prototype for initial feedback. The initial prototypes were made from a carton, paperboard and Styrofoam are shown below.

Figure 20: Low-fidelity Prototype; Testing Session (Source: Author)

The team was split into two, working in trios to work on different concepts. One group used Styrofoam to create a life-size cubed 3D printer while the other group used cardboard to create a rectangular concept. The two concepts were created in 30 minutes, with emphasis on structure as opposed to the actual look and feel. The teams were discouraged from creating complex and elaborate prototypes at this stage.

Testing

Three UoN makerspace users were invited to experience and react to the low-resolution prototypes. The teams allowed the users to interact with prototypes and noted their reactions. They were allowed to ask questions and give suggestions on things they thought should be improved. The team took notes and asked follow-on questions to get as much feedback as possible.

The obtained feedback was unpacked and shared in a feedback capture grid and discussed among the team on how to incorporate them in the next prototype. For instance, one of the users was concerned with the material that would be used for the final product and suggested using aluminium carbide for the casing. Another user suggested using curved edges to enhance the aesthetic look and feel.

The design sprint concluded with a proof of concept, that will be used to seek funding to implement the design. This included CAD designs (see *figure 25* below).

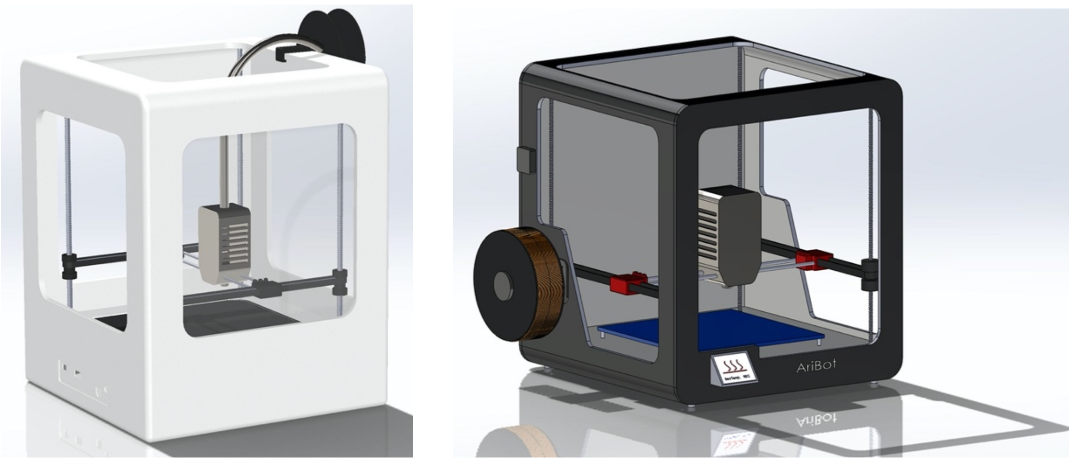

Figure 21: Final Concepts (Source: Author)

The Design sprint brought together a transdisciplinary team at a short notice, ensuring that the final solution benefited from the input of experts from different disciplines. This was new to projects at the space. The Digital Blacksmiths project lead noted that it was different from the process that the was used to and produced results in a short period. The researcher observed that the participants were actively engaged and enjoyed the brainstorming and ideation phase and could be seen actively cracking jokes as the process went on. There were however heated debates on what to add or remove with engineers and designers urging on what was necessary or not. This was different from the engineering process where the product is taken to designers after it has been tested and found to be functionally effective. In cases where they could not agree, Dotmocracy and butterfly technics were used for decision marking. This was done by using pins and chroma labels to select the most popular ideas.

Getting a team of experts to clear their schedules for a whole week to attend the design sprint was however a challenge. To address this the researcher was forced to compress the exercise to four days, with a break on Wednesday to allow the participants to catch up with their functions. After the exercise, the team had to wait for designs to be designed taking more time (1extra week) than anticipated. The product resulting from the design sprint allowed the team to get instant feedback from the makers at the makerspace and was actualised immediately as opposed to having to wait.

4.4.3 Location and Space

The UoN Makerspace is located at a serene environment at CAVS, Upper Kabete around 15KM away from the main campus. Due to a growing demand for more space, the space needed to be moved away from the main campus. The location of the makerspace has proven a challenge to most makers, making it very difficult for them to access the facility. Although the university provides free rides to students thrice every day from the main campus to CAVS and vice versa, it is still demanding to access the facility. In response, the question on the location of the makerspace one participant of the FGD said: "You need the motivation to get here."

For makers who are not students, the need for identification at the CAVS gate can be a challenge. To move resources and tools in and out of the Makerspace is also a task, requiring clearance from the university security office. "…coming out with anything have to have a letter from security." (FGD-C)

The UoN Makerspace has a central machine room that contains machines for prototyping, a learning centre that has a 43-inch television screen for training and a breakout room that is equipped with a 55-inch television for internal presentations. The breakout room houses a mini-café (kitchenette) for refreshments. The machine room also acts as an event space and workshop for makerspace projects with some flexible tables and chairs that are moved to accommodate activities that take place there. The incubated start-ups are situated in the machine room. The store is strategically located next to the machine room to all for easy access to tools and materials.

The space is flexible, with the makers selecting a part of the space that works for their needs, the Digital Blacksmiths, for instance, are located by the door due to the fumes that their filament machine produces while KrisKrafts occupy the space bordering the store due to amount of storage they need. However, Machine Stations (space around the machines) are fixed because the machines are bulky. During events and training, the machine room is converted into event spaces, as a result of the flexible nature of the space.

The space is open for all makers, from Monday to Friday, from 8 AM to 6 PM and on weekends when there are special functions. This allows makers to work during the week. This, however, locks out makers with daytime jobs and classes who can only access the facility on weekends or after work hours.

The makers in the Makerspace like the environment around the makerspace. The serene nature of the space and its location close to green and natural spaces makes it a tranquil space to work in, allowing for noise and fumes from the machinery at the space.

4.4.4 Tools and Materials

The UoN Makerspace serves as a rapid-prototyping workshop and technology incubator for Tech start-ups. The facility offers a range of services including; prototyping services; the lab is equipped with digital and traditional fabrication tools for rapid prototyping and small-scale manufacturing. This allows users to quickly get their ideas to physical products for testing in the market. The majority of the makers develop individual projects using 3D printers, CNC Machines, or the Laser cutter. The UoN makerspace has a variety of tools and machines for use by makers at the makerspace. The makerspace has a Laser cutter, a CNC milling machine (ShopBot; for wood cutting), 13 3D printers, one Vinyl cutter, injection Moulding Machine, a drilling machine, a Modella circuit machine for PCB milling, and a drilling machine. The makerspace has also provided four dedicated computers for design and research with design software, and free hi-speed internet for use inside the lab.

Although all these machines are accessible to the makers not all of them are in working condition; the Injection Moulding Machine and the Tomarch CNC machine have not been set up although they were acquired more than 3 years ago. The machines also suffer constant breakdowns requiring to be fixed from time to time. However, due to the lack of dedicated staff, it can take time to have them fixed. The makers are forced to fix them by themselves.

The UoN makerspace provides the materials for use by the makers, though it takes a considerably long time to procure them. Hence the makers are often forced to buy them. As one maker noted "You have to buy the materials for yourself. and if you want to go to the university, you'll have to tell them six months ahead for procurement purposes or a year before the financial year starts." (FGD-C)

In line with its core mandates, the UoN makerspace offers training services to students and other members to enhance capacity and facilitate them to use the available machines. Training is offered on 3D printing, microcontrollers, Arduino, CNC machining, programming and Computer-Aided Design (CAD). The makers undergo training on using different software like Solidworks and Rhinoceros to enable them to design for different machines in the facility. This is done in liaison with different schools and programs offered at the university. They also offer Idea to Market (I2M) training for innovators and entrepreneurs to generate ideas and successively develop them to products that are ready for the market. The researcher, undertook a three-month training on CAD for 3D printing, using Solidworks 2018 software.

4.5 Conclusion

In this chapter, the findings of the research are analysed. The data collected through participant observation, semi-structured interviews, document analysis, focused group discussion and photographs were analysed qualitatively. The research looks at the makers, the engagement process and the making process at the UoN Makerspace. He also explores the tools and equipment available at the space, the location and working environment available for makers at the makerspace.

5 CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter summarises the findings and draws conclusions and recommendations on the findings of the main objective.

5.2 Summary of Key Findings

5.2.1 Makers and the engagement process

The study found out that the University of Nairobi Students were the majority of makers who made use of the Makerspace, although there were other makers (Enthusiasts, researchers, staff, donor and start-ups) at the facility.

Most students at the facility were from the school of engineering, with only two from other disciplines. Hence most projects lacked the input of multidisciplinary teams. However, the management noted that the Makerspace is open to everybody.

The study also looked at the engagement process between makers at the space. The collaboration was encouraged between makers and could be observed during activities taking place in the space. The seasoned makers were always ready to help new makers and share among themselves. The was a major reason by some members in the space on why they like the space.

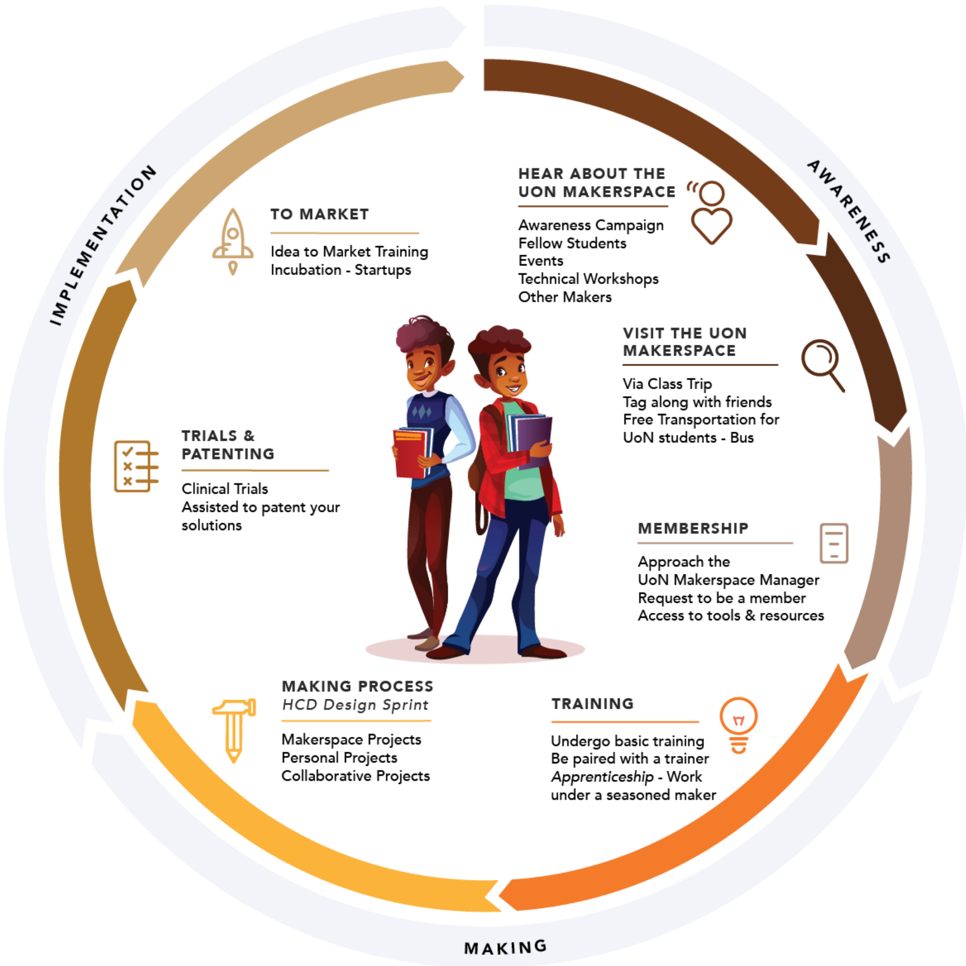

Figure 22: Ideal Maker Engagement Process (Source: Author)

Thirdly, the study found out that there was very a limited awareness of "potential makers" – students, faculty or corporate, of the UoN makerspace, and what goes on at the makerspace. The makers at the space noted that they heard about the space from their friends or lecturers, although the management said that they conduct sensitizing sessions from time to time.

5.2.2 The Making Processes

The study established that the Engineering process is the most used making process at the facility. This was due to the majority of the makers having an engineering background and the makerspace having been started by Engineering faculty. Due to the complex nature of the process, makers from other disciplines found it very difficult to apply.

The makerspace also made use of the Human Centred Design process, although it was used when the donor specifically requested them to use it. In cases where they used HCD, the process was very lengthy, taking up to 8 weeks. As a result, they avoided it terming it as very long and time-wasting.

The researcher made use of an HCD Design Sprint to address the time aspect of the process. The implemented process was short taking 4 days as opposed to the required 5 days of a normal sprint by Knapp et al., (2016). This was because it was very difficult for the participants to clear their schedules for a whole week hence, the process was compressed to allow them to address their work mid-week. The exercise brought all the key product development stakeholders together, allowing their inputs early in the process. This was different from the engineering process where different people were called in when they were "needed". For instance, designers came in after the functionality issues had been tackled to make the product "*look good*". The teams at the makerspace were impressed with the "HCD Design Sprint", and have started using it in new and ongoing projects.

5.2.3 Tools and Materials

The study found out there were some machines and tools at the UoN Makerspace that had either broken down or had never been installed since they were commissioned. Two machines had not been fully commissioned, hence could not be used by the makers.

The research also established that there was insufficient training on using machines and tools. The makers suggested that more could be done to bring the users to speed on utilising the available tools at the space in terms of know-how and training.

The study also looked at the availability and accessibility of materials for use at the UoN makerspace. It was established that the process of procuring materials was very long (requiring at least 6 months). This forced the makers to sometimes purchase their materials for use at the makerspace.

5.2.4 Location and Space

The study found out the UoN makerspace as a space for innovation was very flexible and safe for creation and building. Failure was encouraged, with an emphasis on play and tinkering among the members.

Secondly, it was deemed to be an open space for student makers. The researcher noted that students at the facility were mainly from the school of Engineering with the very few from other disciplines. This was a lack of awareness by students and faculty from other disciplines. The makers at the space had heard about the space from their friends who were using the space. This shows that more needs to be done to make other students aware of the existence of the makerspace and its benefits to the student fraternity.

Finally, the location of the UoN makerspace was considered far by the makers, requiring motivation to access and use the space. Despite the university offering free transport from other colleges to the CAVS, students were not aware of this.

5.3 Conclusion of the Study

University makerspaces are spaces where makers can collaborate and innovate for experiential learning. In a makerspace, makers are the most important component of the space. This study investigated the key makers in University Makerspaces, highlighting the key functions they play in the space. A key aspect of any makerspace the human perspective of the movement is very important. Without people, makerspaces are just workshops with tools. These findings are just an introduction to this area, with further empirical research recommended.

The engagement process by the makers is also identified, showing the ideal user journey of a maker at an academic makerspace. This resulted in an appropriate engagement model to centre makers in academic makerspaces.

The gaps in the engagement cycle at the UoN Makerspace are also demonstrated. Some of the gaps are addressed in this study. For instance, the awareness gap was addressed by the researcher using an awareness campaign, while the making process gap, was easily addressed by an HCD Design Sprint as the ideal making process.

5.4 Recommendation

To centre the makers in academic makerspaces there is need to understand maker and their engagement process in the space. The findings in this research highlight the challenges facing makers in academic makerspaces and identify areas where further research is needed.

The biggest gap in maker engagement process the UoN Makerspace was awareness. Most of the potential makers had not had about the makerspace, let alone what they do. This prompted an awareness campaign targeting students. The campaign ran online using the University of Nairobi Email System and the UoN Makerspace social media Platforms.

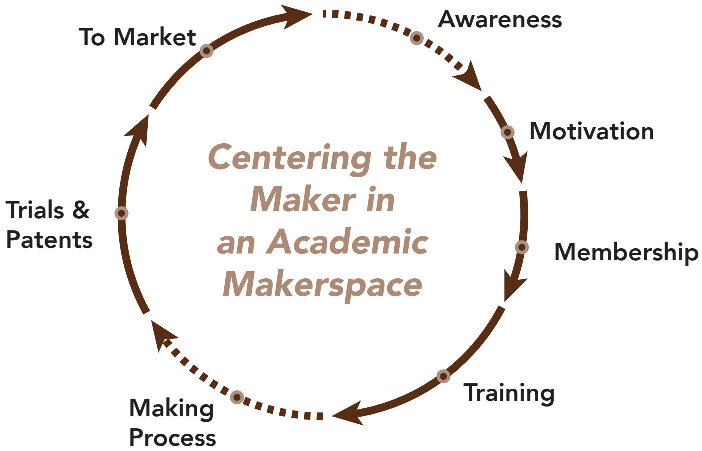

Figure 23: Typical Maker Engagement process at the UoN Makerspace (Source: Author)

The making process was also identified as a key challenge to makers. Makers who did not have a background in engineering struggled to make products as the makerspace forcing others to leave the space. The typical process was considered "too technical" and time-consuming requiring a faster and more inclusive process. To address that, the HCD Design sprint was selected, due to its relatively shorter nature and ability to bring makers from different backgrounds together to create. The Design sprint allowed multidisciplinary collaboration among teams to quickly come up with solutions, prototype and test them.

5.4.1 Awareness Campaign

Figure 24: Awareness Campaign Posters (Source: Author)

An online campaign dubbed "Let's *Make"* to create awareness of the UoN makerspace was launched. The target audience was students and faculty from all the schools and departments of the university. It was designed using colourful and creative artworks to get the attention of the target audience while communicating the role of UoN Makerspace. One of the challenges faced by the makers already at the space was the location of the space and how to get there. This was addressed by the availability of transportation services by the university buses to and from the facility. This was communicated on the artworks.

The campaign made use of an online email platform. This was selected to enable the campaign to reach all the university staff and students who make use of the *uonbi.ac.ke* emails. This was supplemented with social media posts by the UoN makerspace social media platforms on Facebook, LinkedIn and Twitter.

Figure 25: Social Media Campaign Posts (Source: Author)

The Social media campaign, carried a shorter version of the message, considering the time taken by social media users to see and read information online. The email campaign, on the other hand, used more comprehensive posters; showing the activities and the targeted makers of the campaign.

5.4.2 Making process

To address the making challenge experienced by non-technical makers at the UoN Makerspace, an HCD (Design Sprint) making process was proposed. The HCD design sprint allows collaboration among makers as teams have to be multidisciplinary. The process brings all the key stakeholders together from the initial making stages, ensuring that the project benefits from their expertise from inception through to the testing phase.

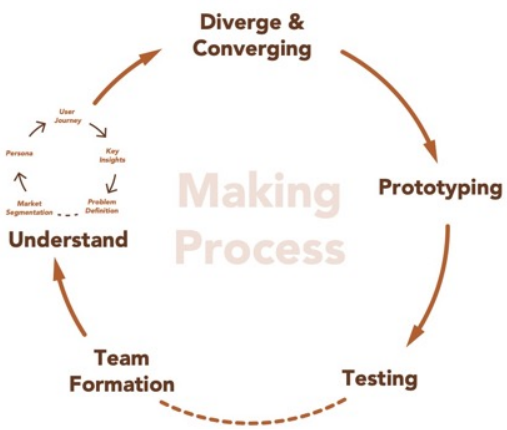

Figure 26: Ideal HCD Making Process for Academic Makerspaces (Source: Author)

The HCD Design Sprint is also versatile; being a relatively brief process (taking only 4 days) allows for quick prototyping and testing of the solutions. Hence can be applied in both time consuming and time constraint projects, with makers coming in and quickly going through the making process to come up with solutions in less than a week.

The HCD Design Sprint process not only centred the maker in the creative process, but it also centred the "end-product user" in the creation process. The *understand* phase allowed the makers to observe and empathise the user, ensuring that the solution is human-centred.

This research looks at makerspaces and makers in depth, bringing to the fore, the advantages that their use in design among other disciplines. It identifies gaps which when addressed will centre the makers in these spaces, promoting multidisciplinary creation in Makerspaces. Hence the contribution of this research to design is both empirical and theoretical, as it paves the way for an in-depth understanding of makers and their experience in Makerspaces.

5.5 Suggestion for Further Research

This study attempted to develop an appropriate model for centring the maker in academic makerspaces. The study focused on the awareness and making phases of the model using the UoN Makerspace. Researchers should look at the training, patenting and "to Market" processes at University Makerspaces to find out whether they are maker-centred. Issues related to layout and space design were not explored.

Finally, further research is needed to establish whether the awareness campaign worked and find out how effective and efficient the "HCD Design Sprint" is in product development in University Makerspaces.

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APPENDICES

Appendix A: List of tools and Materials (Source: Author)

LIST OF TOOLS

Reusable Tools List

JOINING
- Staple gun
- Hot glue gun
- Hot glue gun
- Pop riveter
- Box rivets
- Big sewing needles
- Paint brushes (1" and 3")
- Straight pins
- Splice set
- Tap and die (SAE + Metric)

MECHANICAL
- Screwdriver set (precision)
- Screwdriver set (big) allen (SAE + metric)
- Claw hammer
- Mallet
- Combination wrench
- Ratchet set
- Joint pliers (channel locks)
- Miter box
- PVC pipe cutter
- Socket set
- Driver bits
- Hollow-shaft nut drivers

ELECTRONICS
- Arduino
- LilyPad
- Soldering iron
- Soldering tips
- Crimper tool
- Wire cutter
- Wire stripper
- Diagonal cutter
- Solder sucker
- Digital multimeter
- Solder tip tinner
- 1/2 size breadboard
- Third hand
- Tweezers
- Solder
- Heat gun

CUTTING
- Hole saw
- Metal file(s)
- File card
- Chisel/rasp set
- Tin snips
- Box knives
- X-acto knife
- Scissors
- Drill bits
- Sanding block
- Hacksaw
- Wood-saw
- Block plane
- De-burring tool
- Countersink
- Awl
- Cutting mat
- Hand-crank (rotary) craft drill

FIXTURING
- Vise
- C-clamps
- Bar clamps
- Needle-nose
- Locking pliers
- Adjustable wrench
- Binder clips
- Locking pliers

BATTERIES / POWER
- AA NiMH and charger
- AA NiMH
- 9V battery clip
- 4 AA battery holder
- 3 AA battery holder
- 2 AA battery holder
- Alligator clips

TEXTILE/SOFT CIRCUIT
- Fabric scissors
- Pinking shears
- Seam ripper
- Cloth tape measure
- Sewing needles
- Iron
- Embroidery needles
- Needle threader
- Snap setter
- Serger

STORAGE TOOLS
- Containers
- Labels
- Camera
- Broom
- Dust pan and broom
- Shop Vac

POWER TOOLS
- Jigsaw (electric)
- Sewing machine
- Drill
- Extension cord
- Dremel

EXTENSION
- 3D printer
- CNC mill
- Laser cutter
- Circular saw
- Orbital sander
- Table saw
- Hot wire foam cutter
- Plastic bender

ETC
- Tool box
- Workbench
- Saw horses
- CNC router

Consumable Materials List

ADHESIVES
- Wood glue
- White glue
- Epoxy
- Hot glue sticks
- Super glue (CA) medium + debond
- CA glue thin
- Spray adhesive
- PVC cement

TAPE
- Packing tape
- Paper Kraft tape 2"
- Electrical tape
- Duct tape
- Masking tape
- Scotch tape
- Blue painter's tape

ELECTRONICS
- Conductive thread 2ply
- Conductive thread 4ply
- Bread boarding pins
- Batteries AA
- Batteries 9V
- 9V battery snaps
- Battery holders
- Heat shrink tubing
- Breadboards
- Resistors
- Switches
- Buzzers
- Motors
- Photo resistors
- Jumper wires
- Wire
- Crimps
- Beeswax
- LEDs
- Batteries

WOOD
- @" x 4" x 96" wood
- 4'x 8' 1/4" plywood
- Balsa wood

FLUIDS
- Small plastic syringe
- Plastic tubing
- Luer connectors
- 1-way valve
- T-connector

HARDWARE
- Hack saw blades
- Jig saw blades
- Jewelers' saw blades + lubricant
- X-acto and utility knife blades
- Lubricant
- Acid brushes
- Popsicle sticks
- Paper mixing cups (Solo)
- Plastic mixing cups (medicine)
- Toothpicks
- Caliper battery

ABRASIVES
- Sandpaper (80/200 / 400/600)
- Sandpaper (80/200 / 400/600)

FASTENERS
- Fasteners (screws, nails, etc.)
- Staple gun staples
- Pop rivets
- Mr. McGroovy's Box Rivets
- Zip tie assortment
- Binder clips

TEXTILES
- Thread
- Adhesive tape
- Sewing machine needles
- Felt
- Fabric
- Sewable battery holder
- Snaps
- Bobbins
- Metal beads
- Plastic beads

FIRST AID KIT
- Gloves
- Dust masks
- Safety glasses

MISC
- Shapelock (or Instamorph)
- Nichrome wire
- String
- Rope

Appendix B: Interview Guide (Source: Author)

Date	**Interviews/Observation**	**Aims**
04/11/2019	UoN makerspace project managers, Project leads	Data collection format: Semi- structured interview to establish identify and map out the typical design and stakeholder engagement process in the makerspace and identify the HCD models used at UoN makerspace. Use interview guide with questions to gather data.
05/11/2019 – 08/11/2019	Participant observation	To gather first-hand information. Take photographs and participate in the projects
07/11/2019	Focused-Group Discussion	Data collection format: Semi- structured interview Use interview guide with questions to gather data.
11/11/2019	Design thinking Expert	Data collection format: Semi- structured interview to establish creative facilitation methods used in HCD. Identify the HCD models used for hackathons. Use interview guide with questions to gather data.

Appendix C: Interview Questions (Source: Author)

Research Question	**Interview Questions**
1. Who is a maker and how do they engage with in an academic makerspace?	• **Neutral initial question:** Please help me better understand who uses this space and the role they play at this makerspace. • How did you hear about this space? • What challenges are you facing here at the makerspace? • What is a typical day at the makerspace like for you? • What project are you currently going on at the space? • Who are you working with at the moment? • How do you get new members to join this space? • Any challenges you fame at the makerspace?
2. What is the typical making process at the UoN makerspace?	• **Neutral initial question:** What is the creative process for projects at the makerspaces? • Do you use HCD (Design thinking) to tackle projects at the makerspace? • What creative facilitation methods do you employ at the makerspace? • Who handles the creative facilitation at the makerspace? • What is your experience using HCD at the makerspace?

Appendix D: Focused Group Questions (Source: Author)

Research Question	**Focused Group Questions**
1. Who is a maker and how do they engage with in an academic makerspace?	• **Neutral initial question:** Please help me better understand the role you play at this makerspace. • How did you hear about this space? • What challenges are you facing here at the makerspace? • What is a typical day at the makerspace like for you? • What project are you currently working on? • Who are you working with at the moment?
2. What is the typical making process at the UoN makerspace?	• **Neutral initial question:** How do you come up with new projects? • What is your Creative process? • What creative facilitation methods do you employ at the makerspace? • Who handles the creative facilitation at the makerspace? • Have you ever heard of design thinking? • What is your experience using HCD at the makerspace?
3. What engagement model would be appropriate for makers in academic makerspaces?	• **Neutral initial question:** Have you ever heard of design thinking? • What creative facilitation methods do you employ at the makerspace? • Who handles the creative facilitation at the makerspace? • What is your experience using HCD at the makerspace?
4. What challenges do you face at the makerspace?	• **Neutral initial question:** What challenges do you face at this space • Any attempts to solve them? • What do you think can be done to address them?

Appendix E: Project work plan (Source: Author)

Summary	**Verifiable indicators**	**Means of Verification**	**Assumptions**
1.0 Proposal Activities *1.2 Consultation with my supervisor on the proposed research Area* *1.2 Settlement on research methodology* *1.3 Agreement on activities, timelines and deliverables* *1.4 Submission of research proposal*	Proposal report	Submission and acceptance of the proposal report	

2.0 Data Collection *2.1 carry out desktop research on makerspaces and possible key informants.* *2.2 Literature review* *2.3 Preparation of observation checklists and interview schedules* *2.4 HCD Design Sprint* *2.5 Prepare and submit progress report*	Progress report	Submission and acceptance of the proposal report	Availability of the stakeholders and key informants
3. Data analysis Stage *3.1 Detailed profile of the population to be studied.* *3.2 Engage the population with interviews and site visits.* *3.3 Analysis of data collected* *3.4 Preparation of the first draft of the final report*	Final report	Submission and acceptance of the final report	Availability of the stakeholders and key informants

Appendix F: Budget (Source: Author)

Activity	**Time**	**Unit Cost**	**Total Cost**
1.0 Proposal Activities *1.2 Consultation with my supervisor on the proposed research Area* *1.2 Settlement on research methodology* *1.3 Agreement on activities, timelines and deliverables* *1.4 Submission of research proposal*	7 days	200	1400
2.0 Data Collection *2.1 carry out desktop research on makerspaces and possible key informants.* *2.2 Literature review* *2.3 preparation of observation checklists and interview schedules* *2.4 HCD Design Sprint.* *2.5 Prepare and submit progress report*	30 days	2000	60,000
3. Data analysis Stage *3.1 Detailed profile of the population to be studied.* *3.2 Engage the population with interviews and site visits.* *3.3 Analysis of data collected* *3.4 Preparation of the first draft of the final report*	30 days	1000	30,000
TOTAL			91,400