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BDS 603: PROJECT PAPER

THE POTENTIAL OF GENERATIVE DESIGN IN STANDARDIZATION OF INTERIOR COMPONENTS FOR PRODUCTION OF AFFORDABLE HOUSING UNITS.

By:

Koila Andrew Maitei

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Supervisor:

Dr. Collins. S. Makunda

Co-Supervisor:

Dr. Betty Mwiti

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DECLARATION

This project is my original work and has not been presented in part or in full for an award of any degree in any other university or institution.

Signature...Date 8th SEPTEMBER 2022

KOILA ANDREW MAITEI

This project report is submitted for examination with approval of the following University supervisor.

Signature...Date September 9, 2022

DR. COLLINS. S. MAKUNDA, PHD.

(SUPERVISOR)

This project report is submitted for examination with approval of the following University supervisor.

Signature...Date 12/09/2022

DR. BETTY MWITI, PHD.

(CO-SUPERVISOR)

DEDICATION

This paper is dedicated to all cherished persons who have meant and continue to mean so much to me. To my relatives and friends. A special thanks to my dear parents, whose words of encouragement and push for perseverance still ring in my ears. Silantoi and Sempeyo, my sisters, have never left my side and are constantly supportive.

ACKNOWLEDGEMENTS

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I'd also want to thank the Autodesk community for their assistance in fixing difficulties that arose throughout the study.

ABSTRACT

The focus of this research is on the potential of the generative design in the standardization of interior components in the building of Affordable Housing programme (AHP) by the *jua kali* sectors in Kenya.Generative design employs evolutionary concepts to iteratively enhance design possibilities. To produce solutions and evaluate them against design goals, It modifies the three selection, crossover, and mutation operators.

Through out the course of this paper the researcher looked at different key technologies being developed in the generative design industry. The researcher focuses on componets used in the interior design. This study picked up a curtain rod holder as the main element due to its size and time that was available to the researcher. The researcher then sourced the data from the *Jua kali* sector and affordable housing programme . The data collected and fed to the main genarative design sotware which was Fusion 360 .The software was licensed from Autodesk with educational license. The results and outcome from the process are then analyzed the ways the technology utilized and potential it possess going forward as a design industry.

The inner workings of the generative design process, ranging from ways to help decrease component mass, enhance the performance of their designs, reduce manufacturing process time, and assist them in creating innovative product suitable to the future generation of users who are more concerned than ever with customization and uniqueness.

DEFINITION OF TERMS.

Generative design- The generative design approach is one of design exploration. Designers or engineers enter design objectives, as well as features like as function or space requirements, materials, manufacturing procedures, and cost constraints, into generative design software. The application develops design alternatives quickly by investigating all possible permutations of a solution. With each iteration, it tests and learns what works and what doesn't..(Autodesk, 2022)

Optimization- A problem-solving process that seeks the best solutions to the objective function or functions given restrictions.(IGI Global, 2021)

Genetic algorithm- A genetic algorithm is a search heuristic that is based on Charles Darwin's theory of natural evolution. This algorithm is based on the natural selection process, in which the fittest organisms are picked for reproduction in order to produce offspring of the next generation.(Mallawaarachchi, 2020)

Refinery, - A problem-solving process that seeks the best solutions to the goal function or functions given limitations.

Multi-objective optimization, - Multi-objective optimization (MOO) is a field of mathematics used in multiple criterion decision-making that deals with optimization issues involving two or more objective functions that must be optimized at the same time.(Nayak, 2020)

Standardization, - Standardization has been the operation of creating and recording a limited number of solutions, to actual or potential matching problems, balancing their demands, and intending and anticipating that these solutions would be utilized frequently or continuously, over a specific length of time, by a significant number of the parties for whom they are intended.(H. de Vries, 1997)

Affordable housing. - Affordable housing is defined as housing that can be afforded by those who make Ksh 50,000 or less per month, which represents a total of 74.4 percent of Kenyans working in the formal sector. This definition comes from statistics from the Kenya National Bureau of Statistics (KNBS) on income distribution in the sector.(Cytonn, 2018)

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ABBREVIATIONS

AHP Affordable Housing Programme

AI Artificial Intelligence

BIM Building Information Modeling

CAD Computer Aided Design

CD Computational Design

EPS Expanded polystyrene panels

GD Generative Design

ICT Information and Communications Technology

IDRC International Development Research Centre

IEC International Electrotechnical Commission

ILO International Labour Organization

ISO International Organization for Standardization

KNBS Kenya National Bureau of Statistics

ML Machine Learning

NHC National Housing Corporation

PD Parametric Design

GUI Graphical User Interface

CHAPTER 01

1 INTRODUCTION

1.1 Background to the Problem

Affordable housing is a significant issue not just in developing countries like Kenya but also in many developed nations worldwide. The situation is further compounded by the quick growth of the urban population, the high cost of construction and funding, and rising urban cost of land. (Kieti et al., 2020)

The Kenyan government in 2017 announced an affordable housing program as one of the big four priorities, with a goal of building 500,000 cheap dwellings by 2022 to offer accommodation to all Kenyans.

Housing is a basic physiological need for sustaining life and plays an important role in people's social lives. (McLeod, 2018). Maslow (1943, 1954) asserted that certain needs are more essential than others and that people are motivated to fulfill them. Air, food, water, sleep, sex, clothing, warmth, and shelter are examples of biological needs for human survival. The human body cannot operate correctly if these needs are not met. Maslow thought that physiological needs were most important since, without meeting them, all other wants are subordinate.(Mcleod, 2018) Housing benefits people's health by providing a place to relax and protect them from the surroundings. It also provides security for people and their valuables, as well as comfort, independence, peace of mind, and recognition. (Nzau, 2020)

Individual citizens have a basic need for housing. Housing has emerged as a major concern for many governments in emerging economies, and solutions have been attempted but without success. Kenya's government has tried unsuccessfully to contain the situation through policy action. Demand for housing units continues to outstrip availability due to the crisis.

Less than fifty thousand affordable homes units are supplied in urban centers, according to the World Bank, compared to two hundred and fifty thousand demands as well as a total overall housing shortage as well as a total overall housing shortage of almost two million units. Over sixty percent of Kenyans live in dismal conditions. Slums and informal housing settlements. This settlement lacks facilities, water, and sanitary conditions. These families also have a limited or non-existent budget. Housing costs for low-income people exceed thirty percent of their earnings, leaving them with insufficient money to meet basic requirements like food and shelter.(World Bank, 2017)

The housing crisis is worsened by the differences in social and economic status. Kenya is an extremely unequal country, with a Gini value of 0.48, according to a World Bank assessment (World Bank, 2017). As a result of this inequality, social economic classes such as upper class, upper middle class, and low-income class have emerged. Because the elite and middle classes have significant financial resources, many private and state contractors focus on the creation of dwellings for these strata. Lower-income individuals are caught in the middle, with little access to affordable housing.(World Bank, 2017)

As per a World Bank report (2017), more than eighty percent of housing provision is for the upper middle class, with approximate forty eight percent for high-paying job and two percent for low income. In contrast, demand for high income and middle-income housing is two percent and fifteen percent respectively, whereas lower-income earners demand is forty eight percent, putting a huge amount of pressure on housing supply for the low-income segment. (World Bank, 2017)

The government took a bold step in iterating policies that had been in place for the previous 30 years. When the government first announced the Affordable Housing Program in 2017, (AHP). The AHP (Affordable Housing Program) offers possibilities to a variety of professionals. To specify interior and product design. Standardization of various products is a valuable opportunity that should not be overlooked. The government took the effort to promote *Jua kali* items from the region. The issue occurs because their products do not adhere to any criteria, making it difficult to incorporate them into the Affordable Housing Program (AHP) (Nzau, 2020)

"We are providing artists with the opportunity to assist in the construction of dwellings as part of the affordable housing initiative. The sector contributes significantly to employment in the country and is a critical enabler for the industrial sector. We are eager to upskill them so that they may participate to this national development endeavor while also advancing their careers." Housing PS Charles Hinga iterated in a launch of *jua kali* sub contraction in Nairobi.(Murigi, 2020)

Iterative/generative design provides new methods of visual design experiences in accordance with incorporating system, dynamics into the conception of products, spaces and experiences. In this article, we look at some of the techniques that designers can explore and recommend how generative design will benefit design as a profession to solve some of the problems such as standardization of spaces products in Kenya. Self-organization, swarm and ant colony systems, evolutionary processes and generative grammar are examples of the iterative design processes..(McCormack et al., 2004)

Design discovery is at the heart of the generative design processes across the industry. Designers and engineers utilize generative software applications to insert design objectives, in addition factors such as performance or space constraints, materials, manufacturing processes, and budget constraints. The application immediately generates design options by exploring all possible possibilities of a solution. With each iteration, it analyzes as well as understands what appears to work and what doesn't. (McKnight, 2017)

Many scholars and industries have begun to use Generative Design in a variety of methods, including planning, cost control, and material utilization, among other things, since its inception. Many scholars and industry experts believe that generative design is critical to the future of manufacturing, design, and construction. Different technical advancements, such as Artificial Intelligence and Machine Learning, are used in the generative designs. The utilization of computer power to come up with designs and solve challenging problems is what generative design is all about. The designers must enter goals or limitations such as materials, cost, weight, performance, and form into software, and the algorithm will provide a variety of design options. The designs are then sorted to find those that meet the problem's objectives. (*Generative Design 101*, 2021)

With ongoing public discussions and investigations on artificial intelligence (AI) and machine learning (ML), it appears that using computers in the design process to save time and money is an appealing option. Because computers are objective and non-biased when it comes to critiquing, they will come up with ideas that we never would have thought of and others that are far superior to what we would have done as designers.

When we're asked to come up with a floor plan, a product, or an artwork, we revert to fundamental forms like squares, circles, and rectangles. On the other hand, an algorithm will generate several ideas based on the limitations provided to it. When contrasted to humans, the algorithm will respect the specified goals and changes may be performed rapidly and repeatedly.

As a result, generative designs are here, and now is the moment for all designers to embrace the technology or risk being replaced by it. Generative design can either be the best possible thing that has occurred to the Design and Construction industry, or it can be the industry's downfall. It's all about whether the industry accepts or rejects the technology.

1.2 Statement of the Problem

Generative design is a new paradigm to all industries. Generative design impact us as designers in how we relate and do things in immense ways. This paper aspires to explore on how generative design and iterative design can be used in the interior components to achieve standardization and efficient use of material in local production.

How can generative design technology influence the *jua kali* product standardization process in interior components in order to attain affordability?

1.3 Main Objective

To investigate how generative design can be used in the standardization of production of interior components from *jua kali* sector in Kenya to achieve affordable housing.

1.4 Specific Objectives.

I. To determine the technologies used in the Generative design industry and the methods used.

II. To identify processes of product standardization using generative design.

III. To establish the design processes and procedures used in the informal sector *'jua kali'* in production of interior components.

IV. To develop a framework for using generative design to standardize interior components for affordable housing projects in Kenya's *Jua kali* sector.

1.5 Scope of the study.

The current situation, potentials, and challenges of the affordable housing program are considered for the analysis using the case of an affordable housing projects in Nairobi and involvement of *jua kali* units at the Park Road Affordable Housing Programme in Ngara. Articles, interviews, content reviews of electronic and print media, and government of Kenya published manuals on the affordable housing program will all be used to collect data. Varying generative techniques will be used to aid in the development of plans and standards.

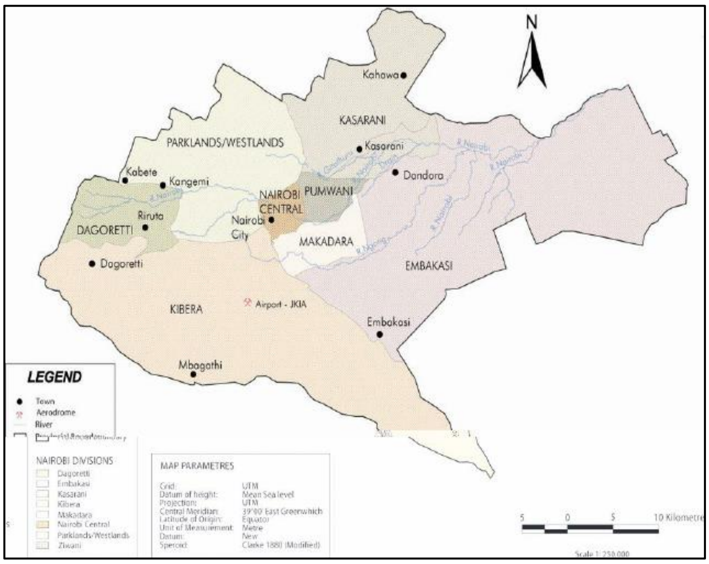

Figure 1 Nairobi County source https://www.researchgate.net/figure/The-map-of-Nairobi-County_fig1_256484690

1.6 Justification of the study

Given that interior designers throughout the world are focused on interior space that is environmentally friendly designs, generative design as a new technology will aid in material reduction, resulting in cheaper production costs and less waste for affordable housing units. Interior designers and designers must also widen their awareness of new technology and how they might improve their operations.

1.7 Significance of this study

The goal of this study was to look into generative design processes and standardization in the production of interior components. Data will be collected from local *jua kali* and housing sector. The research will help to promote knowledge of existing generative design technologies and standardization. Furthermore, the research findings will aid in the understanding of emerging technologies and how they might be implemented at the industrial stage. It will also serve as a guide or point of reference for interior designers interested in learning further about generative design.

1.8 Limitations of the Study

Due to a limited budget and time, the study was limited to interior components produced localy, and thus the study was not exhaustive of the generative design technologies and its application. There were other uses of generative design such as space optimization but the researcher chose to focus on interior components due to their size compared to space sizes and power and resources required for computational processing.

1.9 Structure

The following chapters will make up the study. In Chapter 1, the general research concept inquiry will be introduced. Chapter 2 contains the literature review and hypothesis development. Chapter 3 explains the methodology, which includes data gathered from various sources. Chapter 4 summarizes the findings from both the *jua kali* data and the evolution of generative design models, while Chapter 5 wraps up my research and offers additional research opportunities.

CHAPTER 02

2 LITERATURE REVIEW

2.1 Introduction

A study of generative design and the *jua kali* sector in Kenya is included in this chapter. It focuses on the generative design industry's processes and frameworks, as well as their application to everyday design. It emphasizes the *jua kali* sector's position in relation to the affordable housing program. In this chapter, we will look at the following topics: The essential elements required to comprehend generative design, as well as a definition of generative design within the framework of the Architecture Engineering Construction industry, which includes Interior Design. An overview of Kenya's *jua kali* industry and the project for affordable housing.

2.2 Computational Design

Computational design is not any one algorithm or off-the-shelf process you can utilize. the generative design organization describes it as a process in which a designer creates a set of instructions, rules, and relationships that precisely outline the steps required to complete a suggested design and the data or geometry that results. .(Generative Org, 2021) Several authors define computational design as a method of developing design solutions using digital tools such as CAD programs. (Alfaris, 2009); McKnight, 2017), (Stiny & March, 1981).

According to Antoine, the increased computing capability of tools and the breadth of available computational design approaches have enabled both designers and architects to improve the overall design process, by making it more effective and efficient or enlarging its theoretical limitations. These new methods enable architects and designers to experiment and evaluate alternative sophisticated solutions, develop new production processes, and regulate the design process at various stages in an impressive manner. As a result, the question of whether computational design is positive or negative for design is no longer relevant. (Antoine, 2004)

Caetano, Santos and Antonio, (2020) agree that certain computational methods only rely on computers for solving simple tasks like drafting or vector representational purposes, whereas other processes like simulations providing information for or driving the design process through automated generation make full use of their computational capabilities.

Architects and designers have embraced the computational design paradigm in the last two decades, according to Caetano, Santos, and Antonio., (2020), as a method of improving common design processes and discovering new study strings. The use of computational Design (CD) frequently necessitates technical skills, pressuring designers to acquire new skills from several other fields. The article also demonstrates that computational design has progressed into specialized subcategories, the most common of which is parametric design (PD). Parametric design (PD) allows designers, architects and engineers to provide the important parameters of their projects and make adjustments asynchronously, with the model automatically updating. Parametric design can be used for architectural display, but engineers, designers can use it to create more efficient designs, investigate more options, and optimize projects. The use of parametric design tools has reduced the duration between design research and analytics from weeks to hours. It has resulted in an improved design with a better knowledge of the design structure's essential features. And it has allowed them to investigate the most efficient scheme among the numerous design alternatives.(Citerne, 2020)

The second computational sub-category is generative design (GD). In this chapter, however, the literature will concentrate on Generative Design.

2.3 Generative design

According to some scholars, generative design is a type of design methodology that basically pertains to evolution process used in concept generation as well as production and manufucturing processes. (Fischer& Herr, 2001 , Frazer et al., 2002;), Others define it as design system based on algorithmic or ruled-based techniques which create numerous and potentially sophisticated ideas.(Bernal et al., 2015); (Oxman, 2008); (Chase, 2005); (Fasoulaki, 2008). Moreover, many authors consider techniques like evolutionary methods , generative and form grammars ,cellular automata algorithmic generation, L-systems, and self-organization ((Humppi, 2016),(Shea et al., 2005) Oxman, 2008; Chase, 2005; Fasoulaki, 2008).

After comparing the various perspectives, Caetano, Santos, and Antonio., (2020) believe that the first, which confines generative design to processes of evolution because it is so narrow it exempts many techniques that generate design as well. Generative design must also be distinguished from other computational terms, such as parametric design (PD). As a result, they define generative design as a design paradigm that makes greater use of autonomous algorithmic descriptions than parametric design (PD). When the generative design process begins, the system executes encoded commands until the stop requirement is met. (Caetano et al., 2020)

As a result, GD is a co-design process that involves both designers and computers. Throughout the generative process, the designer describe the design constraint parameters, while the workstation generates alternatives studies, analyzes the results against measurable goals the designers set, enhances the solutions utilizing previous studies' outcomes and responses from the designer, and classifies the results on the basis on how well they accomplish the designer's original goals .(Generative Org, 2021)

The following distinctions apply to generative design, which is a subset of the approach to computational design.

I. The designer decides on the objectives to complete a given design, rather than the exact steps to be followed or taken.
II. The designer uses the computer to explore the design ideas and concepts and generate a variety of design options which vary in number.
III. The designer uses the computer to find a set of ideal solutions that meet different competing interests.
IV. The designer evaluates a variety of design scenarios to identify a set of design options that best meets the design objectives.

2.3.1 Importance of Generative Design

Generative design, according to the Generative organization, is a computer controlled goal-driven approach to design that enables designers and engineers to innovate new things(Generative Org, 2021) below are some advantages of GD ;

I. have a better understanding of their designs
II. to make better-informed design decisions in a shorter amount of time.
III. Using the power of computers, investigate more options.

Better understanding of design.

The designers determine which design outcomes they want to achieve and the way and how they will be measured. The workstation computers generate sets of viable and optimal designs with designers' input, also the data needed to evaluate and determine which design performs best in terms of designers' objectives. Designers can gain valuable insight into which design aspects impact the resulting outcome and how the generated designs compare to the set goals

Faster and better-Informed Design Decisions

Generative design can help designers discover better designs for their project more quickly by taking advantage of what computers are good at: calculation and repetition. Computer workstations can create and assess large volume of design options in a portion of time it takes a single designer if not seconds, enabling designers to understand what functions and what doesn't quickly and fail faster .(Nagy, 2017)

Variety of design Options

The early design variables designers provide are used to generate potential design solutions utilizing generative design technique, the only constraints being designers input , workstation power and time. (Generative Org, 2021)

Designers could, for example, test tens of different options or more using traditional or classical computational design methodologies. An algorithm can generate hundreds, thousands, millions of different ideas in minutes, if not seconds, using newer design methods like generative design.

A Collaborative Approach

The ultimate aim of generative design is to augment creative intelligence of humans with computational capabilities and power, rather than what we human fear most being replaced with computers and robots.(Generative Org, 2021)

A good generative design process that evaluates designs in a study using multiple metrics and parameters will never produce a single output. Instead, it will always generate a set of results which the designer can choose from, each of which will have been objectively evaluated and ranked appropriately. The generative design process makes no decisions for designers.

2.3.2 Generative Design Stages

Generative design mimics the evolution process. It has the ability to "learn from designs it has analyzed and apply that knowledge to generate new, better performing designs" (Nagy, 2017). This technology fits into the bigger context of artificial intelligence owing to its capacity to learn. The genetic algorithm, a type of evolutionary algorithm, is indeed the search algorithm used throughout the majority of generative design studies. It is based on a set of principles. (Nagy, 2017):

Generate stage

At this stage the generative design software or algorithm. creates or generates results based on the constraints fed to it be it material or mass, obstacle, preserved geometries among others. These stages mostly rely on the computational power of workstation but nowadays cloud computing has advanced for the generation process to be carried out by any designer no matter the power of their systems. After that the process is executed and the software to come up with a range of design alternatives

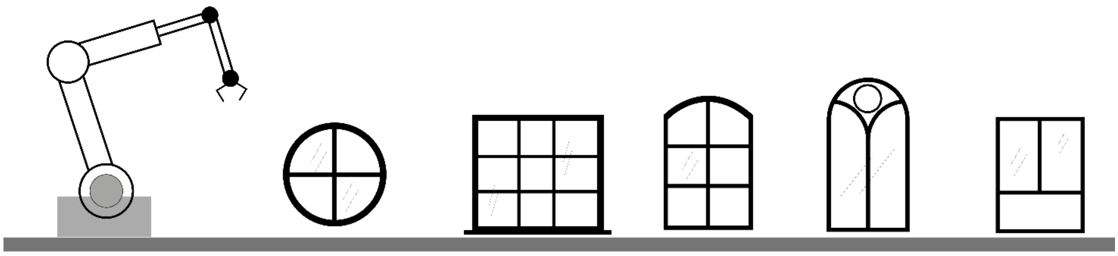

Figure 2 Generate stage source author

Analyze stage

The designs established in the design phase are now evaluated or analysed to see how well they meet the designer's objectives. The software evaluates and ranks all of the design options it generated in this stage using the pre-established metrics. The best answers in each category are then chosen, and they serve as the foundation for the following set. That is how it gains knowledge and raises the general standard of each batch.

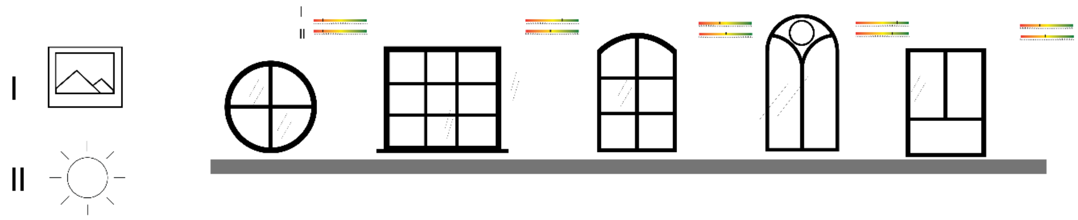

Figure 3 Analyze Stage, source author

Rank stage

Based on the analysis' findings from the previous stage, the design options are ranked or ordered according to the objectives. During this stage the designs that do not meet the Objectives are eliminated or send back to analyse stage or start of the process.

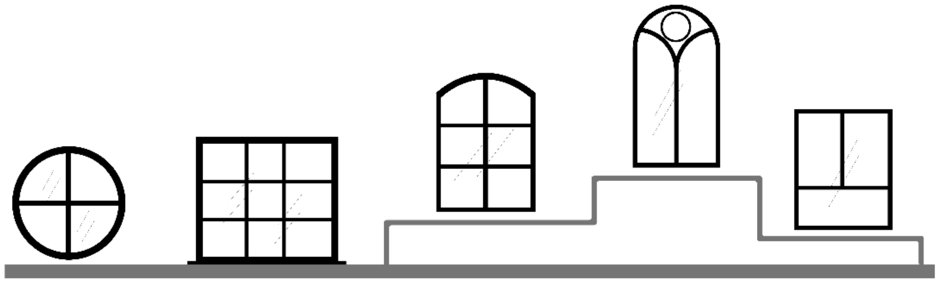

Figure 4 Ranking of results, source author

Evolve stage

The programme selects the finest design options at this stage of generative design and uses them as the foundation for subsequent concepts. This phase's job is to eliminate suboptimal solutions and identify the top ones in each category. To maximize the likelihood of achieving the greatest end result, the designer might need to adjust the search metrics during this step.

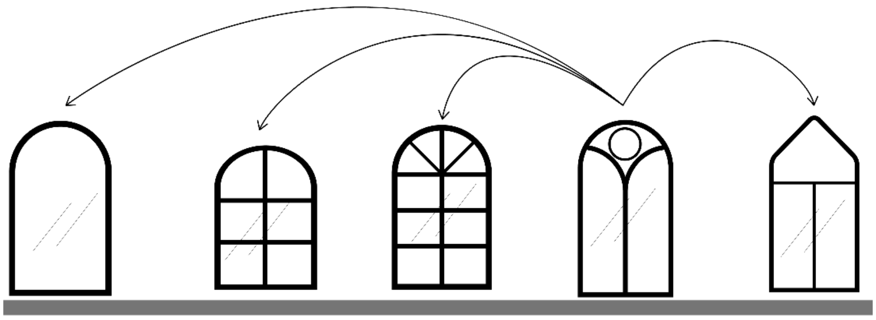

Figure 5 Product evolution, source author

Integrate stage.

A top recommended option is chosen by the designer and integrated into the larger project or design work.

Figure 6 Design Integration, source

The anatomy of each stage

Each of the stages above from generation to integrate can be divided into three sections: define, run, and results. The designer oversees the define step, while the computer oversees the run and results steps. The breakdown of each stage is outline below

Define

The designer is responsible for the following steps in the define step according to the generative design organization:

- Create the generation algorithm, which is the logic that defines how designs are generated and may include constraints and rules.
- Determines generation parameters - these are the factors or data sources required by the prespecified heuristic.

The whole define step is existent and essential for all segments of the generative design process, as the authenticity of results is dependent on the quality of the designer's input in this stage. The computer can provide appropriate outputs with clear and concise data and parameters fed to it.(Generative Org, 2021)

Run

When everything is defined in the algorithm and its associated parameters, the workstation starts running and generating different design options. This process could take place locally on the available system on the designer's computer, or it could take place in the cloud infrastructure for more intensive calculations.

Results

The The final outputs from each stage are the results that are generated during the run step. Following that, these are used as inputs or parameters in later steps. For example, output obtained during the generate phase will be used as one of the input variables in the evaluation stage.

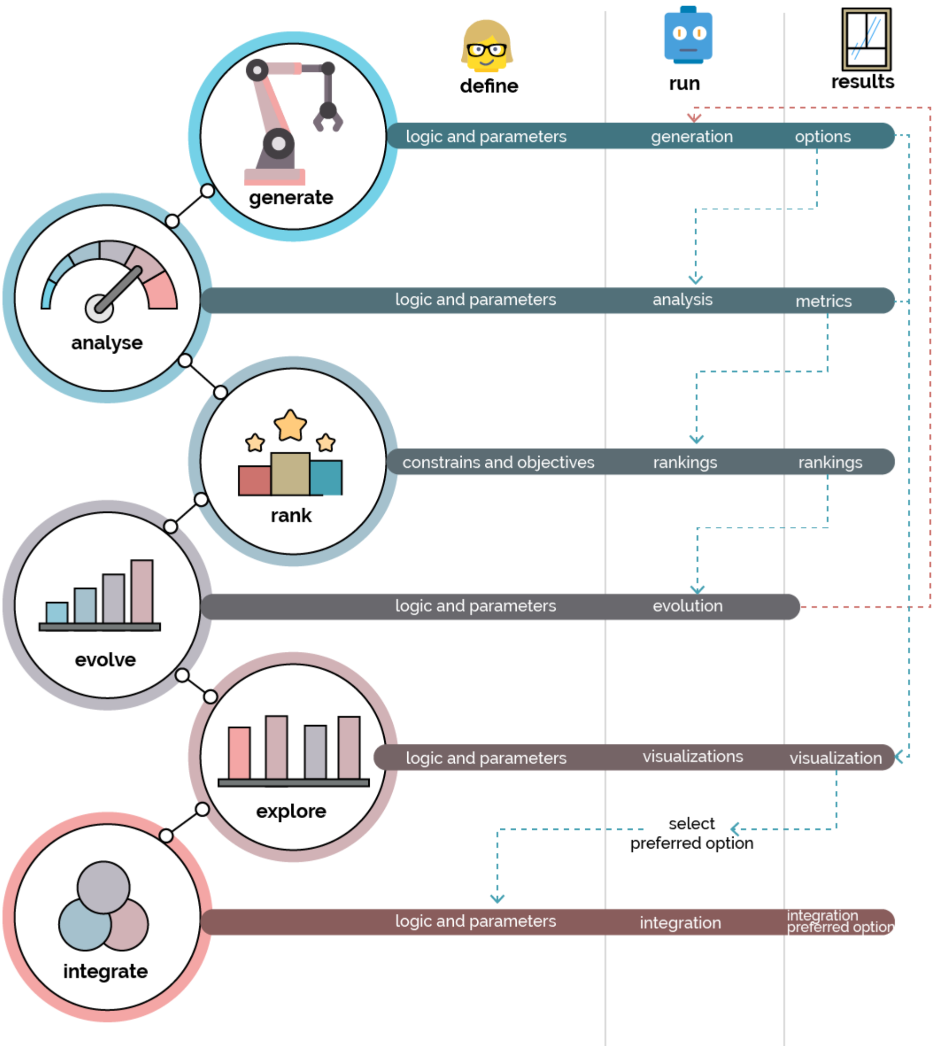

Figure 7 The overall generative design process source https://www.generativedesign.org

2.4 *Jua kali*

A 1972 study of Kenya popularized the term "informal sector," but Kenyans have another term for it: *Jua kali*, which implies "under the hot sun." (ILO, 1972) As an informal industry in Kenya, the *Jua kali* was traditionally managed as small businesses in some African homesteads, usually dealing in blacksmithing (Maundu, 1992)). With the arrival of the Asian traders in Kenya around the early 1900s, there was a continuous change from *Jua kali* activity that is 'home-based' to urbanized enterprises. Motor mechanics, carpentry, masonry, tin smithery, and black smithery were among the first urban *Jua kali* enterprises introduced (Maundu 1992). With the passing years, native Kenyans saturated the market, gradually expanding the industry by producing a wide range of products like *jikos*, cooking and frying pans, metal windows, tin lamps, motor spares, and leather cultural artifacts. The *Jua kali* industry now represents a massive multitude of products in many towns and villages across Kenya.

Kenya's informal system has grown organically in reaction to the need for a large portion of the country's population to gain an income in the shortage of regular employment since these changes. It has surpassed the formalized sectors in terms of employment generation and earnings for the majority of the citizens, Despite a lack of supply of incentive programs and support. The government, on the other hand, has recognized that the informal economy cannot be ignored in past several decades and it has made initiatives to enhance the informal sector growth. (Gikenye, 2014)

Despite its efforts, Gikenye claims that the *jua kali* industry falls short in terms of facilities and infrastructure, particularly in terms of ICT support. Besides the mobile phone, which has been broadly accepted and widely used by Kenyans from all walks of life, most micro - enterprises industries and producers keep relying on primordial technology solutions have yet to adopt ICT technology. Informal sector operators have limited access to computer-based technologies, as the majority lack the necessary skill sets, are unaware of the importance of ICT, and are unable to afford them (ICTs).

According to Osanjo (2012) she agrees that the Internet will be supported by information technology making necessary information readily available to entrepreneurs and artisans. New markets, new materials, and new technology can all be more easily and quickly distributed along the strata of the informal sector. Institutions of finance will be encouraged to participate in the project's activities. (Osanjo, 2012)

2.5 Affordable Housing Programme.

Current landscape

Owning a house is an expensive affair in Kenya, and it's even worse in Nairobi. Perhaps under the Big Four agenda, Kenyans may find reprieve as the government continues its efforts to boost access to affordable housing in the country. (Otieno, 2021)

Seeta Shah's research of affordable housing projects reveals a disconnect between the government's original AHP framework and what is currently being delivered. The only project to provide units after development is Park Road, which does not include social housing units and whose construction costs do not appear to justify the supply price provided to private developers. *Pangani's* flats are being auctioned before construction begins, with large end-user deposits and monthly payments instalment financing. Habitat Heights units are larger and marketed at higher costs than AHP rules, with client deposits perhaps funding the project. River Estate is likewise designed to entice clients to make 100 percent cash deposits. (Shah, 2019).

Regardless of the difficulties, there are still possibilities for inexpensive housing projects. The AHP aims to take advantage of the potential for affordable housing that exist in the country and to overcome the problems that stand in the way of everyone having quality and adequate housing. Kenya offers enormous opportunities that, if properly exploited, might provide its residents with the ultimate home dream.(Nzau, 2020)

The opportunity

There are several investment prospects in the construction of middle and low-income housing, as well as the manufacturing and distribution of construction components and materials. Additional opportunities for providing cheap housing in Kenya involve:

By employing locally available materials and labour, housing costs might be decreased. Housing developments are delayed, building expenses go up, and local businesses, notably those in the Jua kali sector, lose business as a result of the importation of materials, labour, machinery, and other inputs.

Building designs and components should be standardized for industrial/mass manufacture of affordable housing units. This then lead to an opportunity for both contractors and theconstruction idustry at large to come up with standard processes of doing thins.The standardization will lead to low cost products and delivery of projects in time.(Kieti et al., 2020)

The utilization of innovative and alternative building materials and technologies (ABMTs) provides a key potential for delivering affordable housing and establishing local jobs. Alternative building materials technologies such as interlocking and stabilized blocks have a high potential as the resource is widely available across all regions in the country. Others include the expanded polystyrene panels (EPS), the state department has setup an EPS processing plant under the National Housing Corporation (NHC) factory in Mavoko, Machakos County.This is a sign of potential in this area and field of materials processing .

2.6 Standardization

Standardization is the process or procedure of creating incorporating and implementing standards into professional fields, businesses, industries, or throughout the globe. Standards on the other hand are defined as common or pre-defined approaches to resolving issues with products or utilized processes. .(Griffith et al., 2000)

What is standardization, exactly? Different and often contradictory standards are existed for a given product to be standardized. Second, there are various definitions for the term standardization. De Vries (H. D. Vries, 1999) presents four key ingredients for defining standardization:

- The standardization entities are concerned with,
- Standardization is used in the following industries:
- Standardization's goal(s) or purpose,
- The people/parties participate thar are involved in the process of standardization

When examining at different definitions, it becomes apparent not all definitions adequately address every of De Vries' four elements: According to the International Standards Organization and International Electrical Commission guide: "Standards are documents, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context"

(ISO, 1996). The above definition speaks on the objective but not the persons, entities, or sectors involved, aside from providing a general classification.

For instance, Lee and Jang define standardization. "as the degree to which work rules, policies, and operating procedures are formalized and followed" (Jang & Lee, 1998), clearly not addressing all four key elements by De Vries.

Adding to the discussion of various other efforts to define standardization , The following is De Vries' holistic definition of standardization: "Standardization is the activity of establishing and recording a limited set of solutions to actual or potential matching problems directed at benefits for the party or parties involved balancing their needs and intending and expecting that these solutions will be repeatedly or continuously used during a certain period by a substantial number of parties for whom they are meant" (H. D. Vries, 1999, p. 155).

There are a variety of contributions and techniques to standardization principles available today across different industries. Systems, structures, and architectures that are modular that focus on product standardization are the most popular concepts; however, there are many other concepts that deal with manufacturing technology and process design. The goal of increasing efficiency and lowering costs per output, as well as Production costs and engineering costs, is shared by all approaches. (Tassey, 2000; Yu et al., 1999)

Aside from an obvious cost reduction, standardization has a number of positive indirect impacts, including transparency and openness due to a high degree of knowledge about product and process relationships and, as a result, less sophistication. (Tassey, 2000; Ulrich, 1995).

After a case study on standardization Münstermann and Weitzel, production processes became faster, for example, service processing time, and time to market for new services and service packages were drastically reduced. The implementation of uniform processes across formerly differentially produced business units, locations, and service kinds in the case study showed increased the overall service package quality. Standardization of the manufacturing process resulted in reduction in production costs in the study.

2.7 Conclusion.

From the literature reviewed Generative design is not a more of an organic process. The constrains of a given component are fed into algorithms and software to aid designers' engineers and architects to come up with solutions in faster and easier way. The literature also informs on different aspects of affordable housing and opportunities it presents for *jua kali* artisans and the designers and emerging technologies as a whole. The researcher developed a conceptual framework to tie down all these fields together as shown in *figure 8.*

2.8 Conceptual Framework

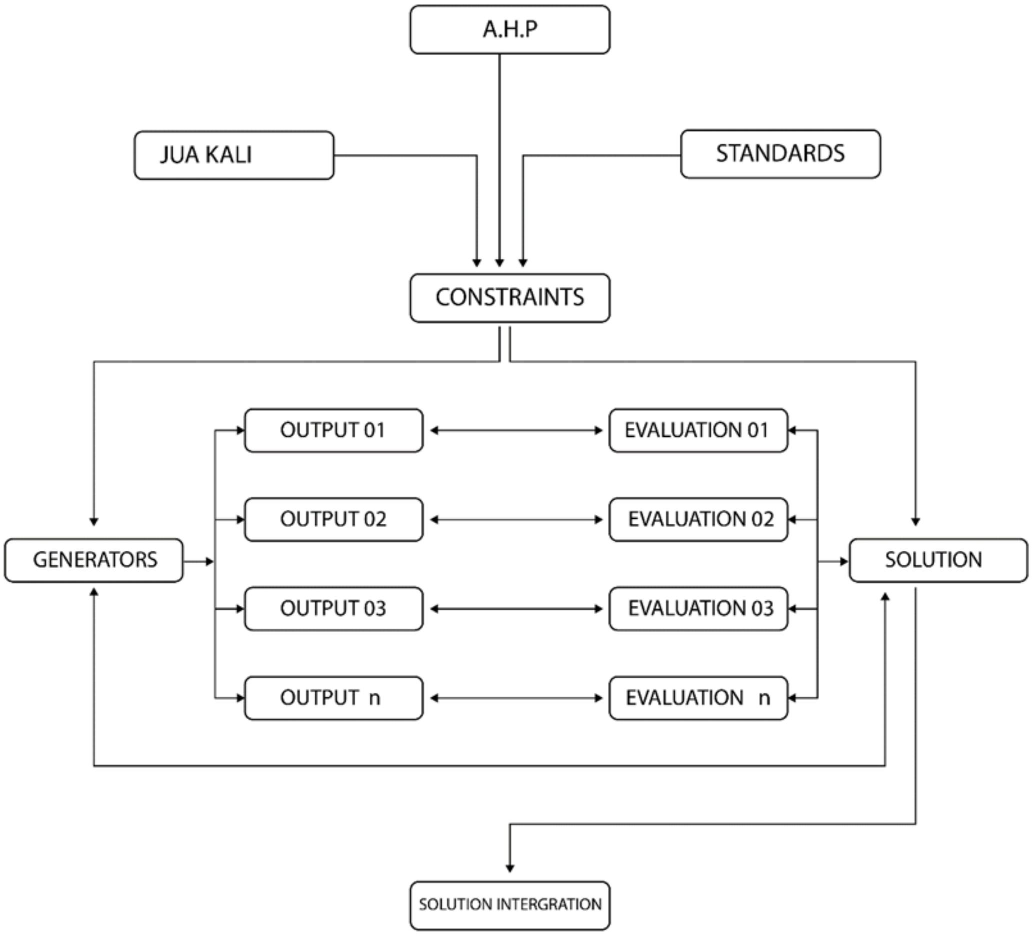

Figure 8 The conceptual Framework, source author

CHAPTER 03

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter will be discussing research design the researcher used, research approach that was utilized and method, data sampling method, data collection and tools to used, population sample was studied, data analysis techniques and presentation techniques that were used to come up with the data.

3.2 Research Design

This research used Comparative Design method. A comparative study is a method that analyses phenomena before grouping them to find points of differentiation and similarity. (MokhtarianPour,2016). According to Turner comparative research design perspective reveals flaws in research design and assists a researcher in improving research quality. Comparative research focuses on similarities and differences between units. (Holt & Turner, 1970).

The comparative design research can be analyzed and categorized in methodical terms. Revising and expanding on Z. smith four-fold of description, redescription, and rectification (Smith 2006). There are five operation that are included in the comparative design process: selection, description, Juxtaposition redescription, verification and theory formulation. Most activities occur in unexpected manner in the research process, but some must logically proceed others for example an event cannot be redescribed before it has been described. It is important to note that not all comparative studies include the five linear steps, it depends on the goal (Freiberg 2019).

The researcher chose comparative research design since it opens ways of selection of the many generated results, their description and redescription until an agreement is reached on the similarities they possess with the data from the field.

This method enabled the researcher to compare the two varying aspect of generative design and *jua kali* production methods in production of the affordable housing components. According to Willie Tan To make conclusions, comparative research compares and contrasts different situations currently generative design and jua kali.

3.3 Research Approach and method

In this study, the researcher will employ both mixed - method approach. According to Leedy & Ormond, 2005 qualitative approach focuses on natural phenomena that occur in natural settings in the real world, such as the integration of newer technology in Kenya's informal sector. The study of *jua kali* operation and generative design from all perspectives will be included in the research. Qualitative researchers will not attempt to modify the observation. Instead, the researcher will attempt to comprehend the issue under consideration, as well as the dimensions and perspectives of the two phenomena. .(Leedy & Ormrod, 2005)

As for the quantitative approach the researcher will administer a questionnaire to 15 enterprises from the *jua Kali* sector via google forms. The questionnaire is designed to answer possible variables where generative design could be used to design interior components that will be used in the construction of Affordable Housing Project in Kenya. The variables include the cost, time and material used in the making of interior components such curtain holders. This enables the researcher to equate the potential of generative design in the standardization of interior components made by the jua kali sector as part of the initiative for the Affordable Housing project in Kenya.

3.4 Population

The sample population used in the research was 15 *jua kali* vendors from the Nairobi environs. The affordable housing project that was identified was *Ngara* housing project along Park Road *Ngara*. The component range was narrowed down to a curtain rod holder which its information was used for generative design purpose.

3.5 Sampling

Tan argues researchers have to select cases properly to make a more persuasive argument A basic principle is to select diverse or dissimilar cases. A second principle in comparative sampling is to select both successful and unsuccessful cases. Finally, the researcher should be aware of reverse causality in comparative studies .(Tan, 2018)

At the site in Ngara the researcher used purposive sampling method to come up with a component that generative design will focus on. At *Jua kalı* vendors the researcher uses the method of convenience to fill in the questionnaires and collect further information on the curtain metal rod holders.

3.6 Data Collection tools

This research combines quantitative and qualitative methods, as was already mentioned. According to Leedey and Ormond, qualitative researchers select one or a few variables to examine the internal components of the research case, after which they gather information directly pertaining to the component variables. Data from the population's variables or from one or more samples that are representative of the population that can be easily transformed to numeric indices for analysis and simulation to provide findings that can be presented and interpreted appropriately. (Leedy & Ormond, 2005)

Data gathered will be automatically computer-processed after using google forms to administer the questionnaire. Frequency count, mean, and standard deviation were used as descriptive statistical techniques.

3.6.1 Observations; & Interviews

In qualitative research, observations and interviews are commonly utilized to collect contextual details and delve further into a respondent's viewpoints, interpretations, and experiences. Quantitative researchers tend to use questionnaires, standardized tests, physical measuring instruments, and simulation. Both types of research review existing documents for qualitative and quantitative data. (Tan, 2018)

Many studies collect data using numerous or mixed approaches to capitalize on the strengths and mitigate the shortcomings of each data collection method. (Blake, 1989)

The researcher collected data by observing:

- the space or physical arrangements, such as the hierarchical arrangements of the affordable housing units, components of the space.
- the people, in terms of the number, composition, and their behavioral patterns. the goals, or what they are trying to accomplish. and their actions.
- the activities carried out in the space.
- traces of frequency of use of equipment within the facilities.
- flows of people or traffic /circulation

3.6.2 Use of physical instruments.

According to Wilie Tan physical instruments are widely used in the natural sciences to measure velocity, acceleration, temperature, distance, mass, pressure, weight, volume, and so on.(Tan, 2018)

The decision for which instrument to be used in the field depended on factors such as cost, availability, accuracy, precision, ease of use, calibration requirements, and reliability. The resecher utilized the following instruments.

INSTRUMENTS	REASON FOR USE	VARIABLE
Rulers	Measure small distances	Distances-length width height
Digital measuring tool; Lidar scanner in iPhone	Measure longer distances and volume and acquire geometries of components	Distances and volume measuring
Weigh Scale	Acquire weigh for materials used	Weight.

Table 1 Instruments that were used in the research.

3.6.3 Simulation.

A simulation model is a mathematical imitation of a real-world system. Researchers use simulations to analyze uncertainty, generate statistical distributions, model processes, generate forecasts, or model interactions among variables. It generates its own data, which makes simulation a method of data collection.(Tan, 2018) For example, we may simulate the energy performance in a building using the design drawings and use the results to improve the design before the construction stage.

The designer will use the following software's for simulations and generative design.

SOFTWARE	**USE CASES**
Fusion 360	The resecher used the inbuilt optimization tools and algorithms to come up with designs
Generative Design	The resecher used the generative design engine for the study purposes.

Table 2 Simulation software's that were used

3.6.4 Review of documents

The researcher collected data from different Published documents in different Autodesk forums to solve different huddles of generative design that were encountered. Academic journals and publication on generative design such as generative design primer from Autodesk were used and also for affordable housing project different article magazines from media and the Ministry of housing were used to get necessary information for the research.

CHAPTER 04

4 DATA PRESENTATION AND ANALYSIS

4.1 Overview

The chapter focuses on analyzing the data obtained from the study on generative design . The findings are centered on the results obtained from the simulations, observation from *jua kali* and questionnaires. The simulation and generative data were generated and evaluated by Autodesk Fusion 360 generative design which was previously Project Dreamcatcher. The findings are presented in charts and themed tables. The descriptive analysis for the charts is shown above the pie charts. The researcher concentrated on generative design data simulated in Fusion 360 and began preparing it for analysis and interpretation. The author contributed to the study by emphasising the process of generative design and some of its applications to design areas and issues. Furthermore, the author explains the technology in such a way that persons who are not technologically savvy may grasp and apply this emerging technology.

The study further went to investigate on the way of operation of the *jua kali* or the micro, small and medium enterprises (MSME) within Nairobi to gauge on their production process to and to obtain insight of data to be feed into the generative design process.

4.2 The *jua kali* process

From the research, there is no pre-defined process for *jua kali*. All the processed are determined by the need at that time, and the client needs. This then make their products vary from one product to another. The formal sector compared to the *Jua Kali* have a standardized process and way of dealing production of products. The generic process in the informal sector is as follow:

4.2.1 Meeting with Client

The Client comes with the idea whatever they need and describe it to the artisans. If there are images drawing or templates the better, the artisans can start from there. The measurements are generated from this example from the client. The colour and material are also determined by clients wants and the price they are willing to pay.

4.2.2 Drawing and Measuring

From the interpretation the Artisans start the doodling. Most artisans have no training in making working drawing. The doodles are the one used as guides. The doodles are adjusted accordingly along the process.

4.2.3 Cutting stage

The artisan then selects the materials to be used and start measuring and doing the cuttings according to the doodles made. The cuttings are then categorized with the gauge of material and templates used. If the cuttings are repetitive the first is used as a template which tend to introduce errors since tolerance of the object being cut keep on increasing with every iteration.

4.2.4 Joining and Bending stage

After cutting and templating the joining and bending stage occurs. Bending depends on product being made. Jigsaws that are pre-made by the artisans themselves are used in the bending process sometimes the use mallet and rails. After bending joining is done mostly by welding or use of rivets and nails.

4.2.5 Finishing stage

After the product has been joined the finishing stages begin with grinding of coarse and filling any gaps introduced during welding or by the welding rods. After grinding and polishing an undercoat is applied to protect the metal mostly red oxide is used by most *jua kali* artisans and finally colour is applied for aesthetic purposes.

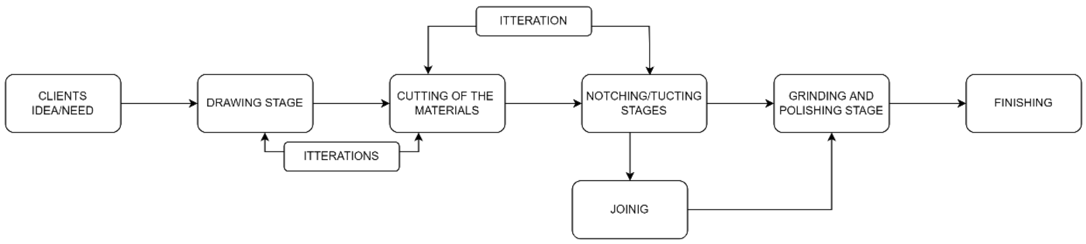

Figure 9 Jua kali Design process; source author.

The data that was collected from the field is summarized below into the cost of material, material waste production, duration it takes for the designers to come up with products. and consideration to integrate Computer aided design in the production process.

4.3 The cost of production

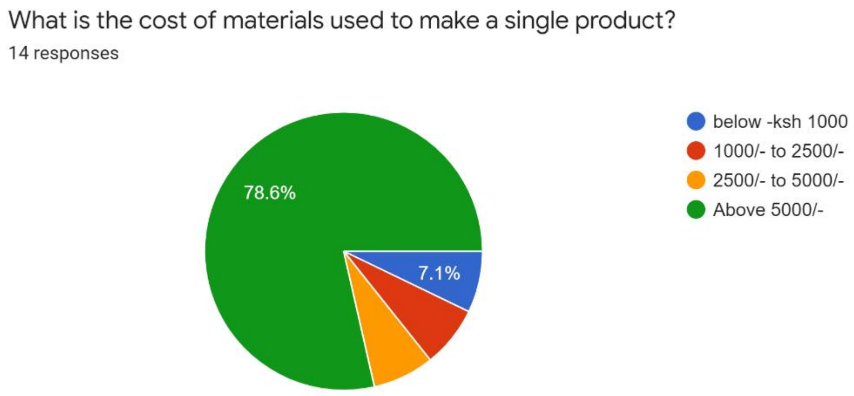

Figure 10; Cost of material used to make component chart, source author

The *jua kali* production when creating a product or offering a service, production expenditures are incurred. A wide variety of costs are included in this. Vendors of jua kali, for instance, incur production expenses for the consumable manufacturing supplies, labor, and raw materials needed to make the product. They also incur general overhead costs.

From the response of the *jua kali* (MSME), 78% of them from admitted that the cost of production of their products was above 5000ksh. The other 14.2% of respondents produced their products between a 1000ksh to 5000ksh.The remaining 7.1% responded with producing goods at a rate lower than a 1000ksh.

4.4 Material waste production in *jua kali*

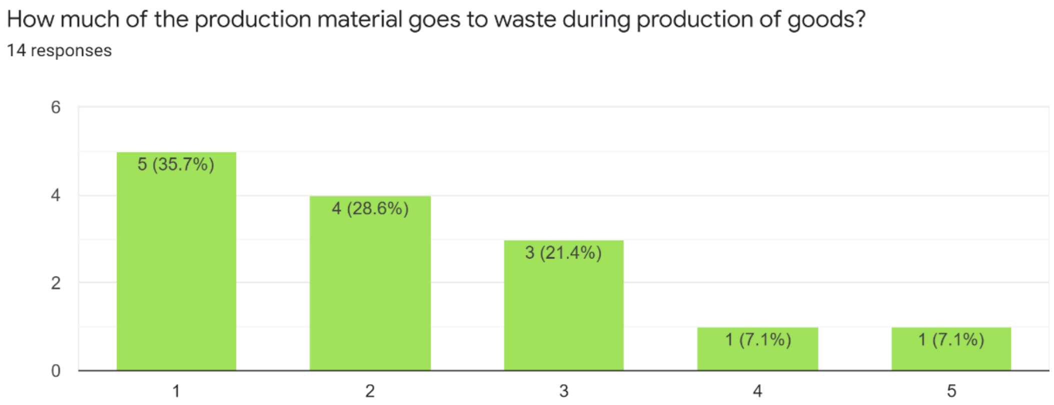

Figure 11; Material waste production chart, source author

Saving material is a huge deal to the *Jua kali* sector (MSME) to attain profitability. All nations, including Kenya, have serious problems with waste creation and managem ent since it has an impact on society, the environment, and the economy. The waste in the jua kali industry is a barrier to social and economic advancement since it endangers human health and environmental quality.

From the respondents 35.7% of them tried as much as possible to maximize and reduce the materials going to waste during production. 21.4% respondent that moderate material went to waste white 7.1% of the total respondents responded with a lot of material going to waste during the production process.

Some respondents also turned to the recycling. Instead of throwing away the waste material they had to find other uses for making profit out of what is deemed as waste.

4.5 The duration it takes for *jua kali* to design a product

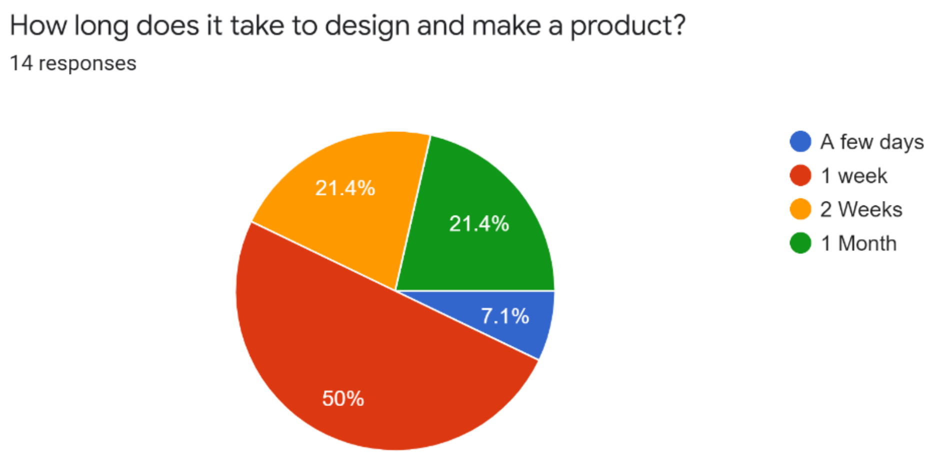

Figure 12; The duration it takes for jua kali to design a product chart, source author.

The design process varies from individual enterprise to companies or *Jua kalis*. The longer the design takes to process and prototype the longer it takes to get to the market and thus experience of loss.

The respondents had come mixed responses on the time it takes to design products. 21.4%. of the respondents said it took the more month to come up with a design and process it to final product. 21.4% also took more than two weeks to come up with designs of their products. 50% of the respondent, took more than a week while 7.1% took a few days to come with the products designs.

A few of the respondents who took more than two weeks to a month argued that their design process took long since they did not want to make mistakes and end up absorbing the cost of the materials they used. They were of the idea of the longer the design take to process the lower the risk of making a loss

4.6 Consideration of *jua kali* to intergrate CAD in production process.

The respondents were asked about their proficiency in the Computer Aided Design or if the know how to use computers. Majority of the respondents said that they know how to use computers.

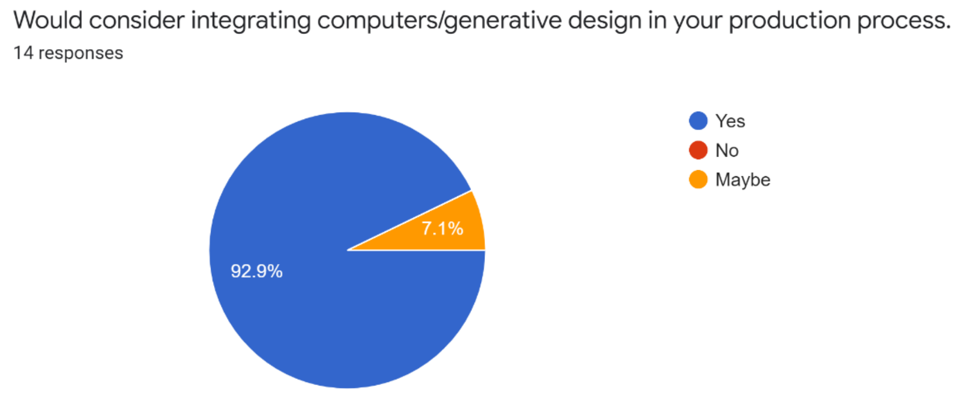

Figure 13; Consideration of jua kali to integrate CAD in production process, source author.

The enterprises were also questioned on whether they will integrate are or are willing to integrate computers and CAD in their day-to-day work. 92.9% agreed that they would consider integrating Computer Aided design in the production process they use on daily basis.7.1% of the respondents were in a stale of maybe integrating computer aided design in their productions.

4.7 The generative design process used

While most processes are conducted on the user's own desktop, all optimization and analysis are completed on cloud services. The GD framework's phases are quite like those found in topology optimization. The main difference is that, initially, a number of forms must be "explored" in order to get the best answer. The phases that come next can be used to organize the overall process.

•**Objectives** – As an analysis goal, user can choose between two options: minimize mass and maximize stiffness. The designer must additionally specify a target weight for the optimization if they choose the second option.

•**Geometry** – During the generating process, the user chooses which portions should be kept and which volumes must remain unfilled (Obstacle regions) (Preserve areas). The initial volume (Design space), which is optional, must be gradually reduced. It is possible to start the optimization by using a feasible Starting Shape to guide the process, although this depends on the design.

•**Load cases** – Forces, pressures, and bearing loads are all supported by generative design. Gravity is also factored into the equation. Fixed, pinned, and frictionless limitations are among the options. The solver can consider several load situations, but dynamic parameters cannot be incorporated. To preserve regions, all loads and limitations must be implemented.

•**Manufacturing constraints** –The designer may specify manufacturing constraints to restrict the research on shapes that can be manufactured using a certain method, such as additive manufacturing, 5-axis milling, or 3-axis milling, hence lowering the production costs of part fabrication. These technologies are not currently available to the *Jua Kali* sector.

•**Material** – Up until now, only linear-elastic models could be used. In a single analysis, GD allows for the simultaneous selection of up to ten materials.

•**Input Check & computation** – GD verifies that all required data is given. If you select yes, cloud computing services are provided after you pay a set charge (cloud credits) in this research the researcher had educational license from Autodesk.

•**Results** – The findings are available to the user once they have been downloaded to the local workstation; depending on the optimization settings, the results could be in the dozens.

•**Exploration** – GD provides a specific environment with visualization tools that enable the user to discover the best feasible option by mapping the results in an organized manner. The mechanical and physical qualities of the outcomes can be plotted.

•**Selection** – From the visualization environment, the user selects the best design and exports it for the required behavior.

•**Export** – The isolated design is accessible to the designer/engineer for future adjustments, and Fusion 360's modeling environment is loaded with the part's CAD geometry. This step is costly since the program charges extra for each design that is exported from the visualization environment.

•**Modification** – After the design has been exported, it should be modified using standard CAD software to fix errors that are frequent in intricate designs with several boundary representation surfaces. This is also necessary in applications of topology optimization, where the tessellated shape generated by the optimization must be adjusted and enhanced before manufacturing can start.

•**Validation** – A further analysis must be done to verify the exported shape's performance. When comparing generated findings from the exploration phase with the final design, several inconsistencies can be observed that are independent of the alterations made in the earlier phases. Therefore, a validation is often advised to evaluate the part's final mechanical characteristics.

The user is helped in completing all of the procedures by a simplified GUI that suggests the processes in a chronological order. Additionally, the user is warned by a series of automated intermediate controls that there may be data lacking that is required to do a subsequent job.

The Study Case

The Affordable housing project presents different opportunities for *jua kali* enterprises and vendors. These opportunities range from different household items from kitchen, bathroom living area and also the construction of the buildings and interiors. Earlier this 2019, the State Department of Housing and Urban Development engaged three Nairobi-based *Jua Kali* organizations (*Ngokamka Jua Kali Group*) to design an integration model for MSMEs in a trial phase. (Khaduli, 2019)

The Group was awarded a contract to provide 8,400 windows and 7,000 doors to Park Road, the first flagship project under the Affordable Housing Programme. The first phase of the Park Road project, which included 228 apartments, was just finished, and the units' used doors from the Ngokamka Group.

The researcher ought to study the potential of generative design and how it can be used by the jua kali production chain. The study could not tackle all the products big products like the windows and doors which are part of the AHP tender.

The researcher chose to study the curtain rod holder for the study since the time for research was limited. The limit in time brought in several challenges. The first, that was encountered was the model upload time. The upload was determined by the bandwidth, which at sometimes was not stable meaning uploading object and meshes would take a lot of time for bigger objects like doors and windows. At times the researcher would resolve this by using local workstation which would even take longer compared to the cloud services that are offered by Autodesk. The metal rod curtain holder is a lighter mesh compared to doors and windows thus offering the opportunity to test the generative design process.

4.8 The case

The curtain rod holder was chosen from the wide range of interior components as the design problem to evaluate the Generative design capability and functionality. The interior component to be studied and generated is a curtain rod.

The general geometry and proportions of the rod at located in the figure 14. The general objective to reduce the component weight within. constraints set in table 4. A static load of 500N perpendicularly to the point of rod support. A safety factor of two was chosen

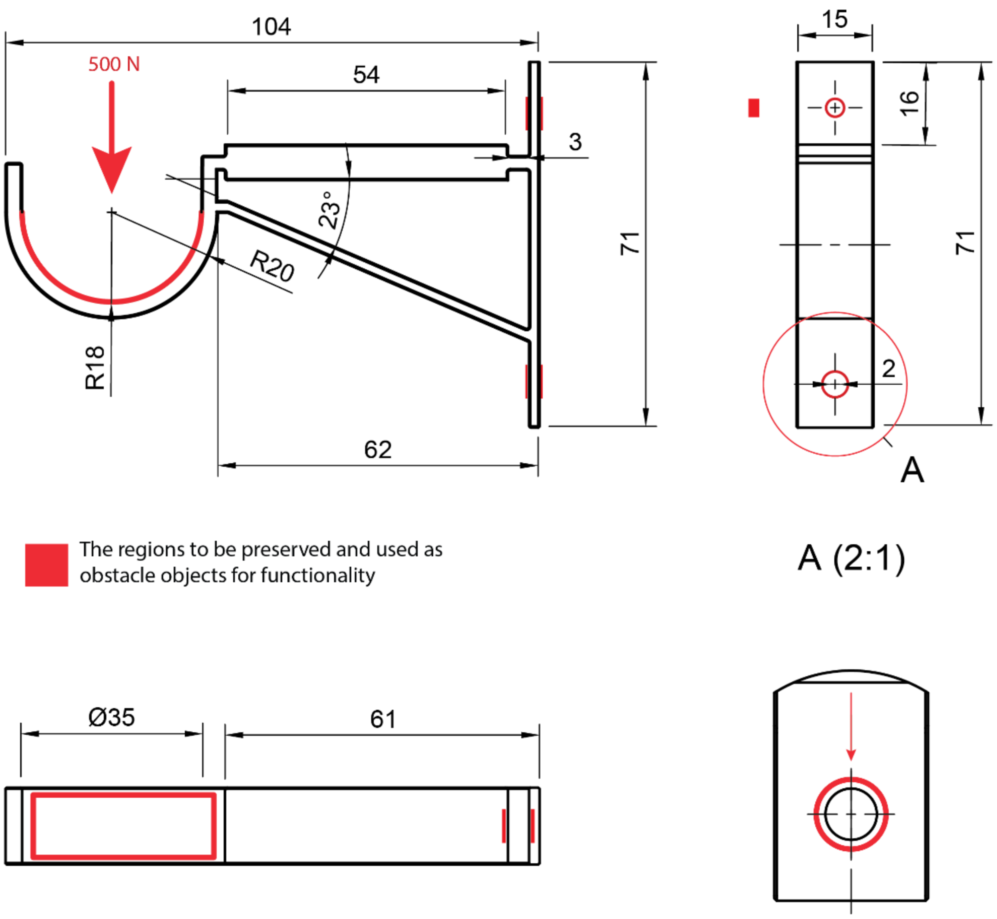

Figure 14 Orthographic Views of the curtain rod , source author

for the study

Parameter	Value
Force Applied	*500 N*
Materials	*Aluminum/steel*
Safety Factor	*>2*
Additive	*5*

Table 3 The parameters of the Curtain rod used

The figure 15 below shows the generative design parts set in fusion 360. In fusion the designer must set the different parts of the object to be either preserved this are primarily the holes for nuts, sitting areas, handles or any features that cannot be eliminated they are marked in green. The obstacles also are avoided parts by the generator marked in red. The loads are then determined by the load to be carried up by the component in this case the curtain load of five hundred newton force was set

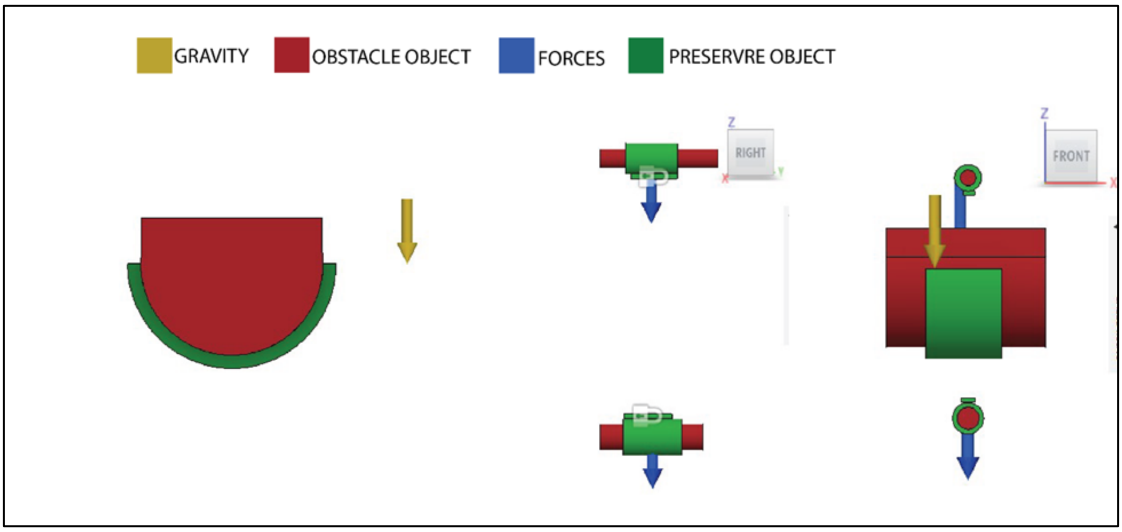

Figure 15 Determined component parts for the generators to adhere to. Source author.

The GD framework was used to test the features of the software on the specified test case. It is crucial to stress that the goal of this research is to evaluate the features offered by the GD tool rather than to do a straightforward component design activity. Therefore, while the portion optimization will be completed in line with, a wider perspective will be kept in order to comprehend how the tool may be used outside of the specific research.

Regardless of what the needs of the case study there were 4 distinct materials and manufacturing processes were incorporated to the analysis to take into account as many elements as possible. The materials were selected from the Fusion 360 collection starting with materials similar to the A36 steel required for the challenge and moving to high-performance materials (e.g., Ti6Al4V, AISI304).

Four options were considered as production technologies: additive manufacturing, 5-axes milling, 3-axes milling, and unrestricted. Every technique place certain limitation on the final product's design.

Milling, for instance, necessitates that creation of a tool geometry to compute volumes to leave vacant to allow tool access. Overhang surfaces are considered in additive manufacturing. On the other hand, the unrestricted modality refers to an unrestrained optimization.

The generative design analysis. brought about a generation of 16 and genomes of average 20 per generation. Tables 5 and 6 below show the candidate solutions. Generative design differentiates between solutions that have been completed and those converged. The finished results have been generated, but they either don't meet the design criteria specified or the geometry in the study didn't work. The results generated were not always to expectation others are practical while others are not.

Manufacturing constraint	Results
Unrestricted	*5*
5-axes milling	*1*
3-axes milling	*5*
Additive	*5*

Table 4 : Number of solutions produced by the GD depending on the material.

Material	Results
Aluminum 6061	*3*
Aluminum Alsi10Mq	*7*
Titanium 6Al4V	*3*
Stainless steel AISI 304	*3*

Table 5: Number of solutions produced by the GD depending on the material.

4.9 Scatter Graphs Results

The software's automatically created graphs, which enable an effective mapping of the solutions, will be used to examine the solutions. The user can choose which parameters to use on the axes and how to group the solutions to find general trends. Figure 11 depicts an illustration of how the answers produced by the analysis are plotted in terms of mass vs. maximum displacement. These graphs serve a purpose since they allow dynamic comparison of solutions with considerable differences in a variety of parameters, such as material, manufacturing process, and macroscopic shape, among others. Given the large number of solutions the GD research at the time yielded this phase is essential.

Figure 16;Results dispersion graph produced by the GD exploration environment, mass vs max displacement, solutions grouped according to the material.

The graph above shows the maximum. mass displacement of material used by the generative design process. in relation to the mass of the material used in the generative process. Most materials started with high mass which resulted of to low displacements. Alumininum started with a mas of 0.17kg and a displacement of around 0.7 at generation 1. At the 50th generation the aluminum had a displcement of aproximately 0.16 while staineless had a displacement of 0.05 at the 50th generation. This shows the different features of materials under stress

Figure 17; Results factor of safety produced by the GD exploration environment, minimum factor of safety vs total volume, solutions grouped according to the material

The graph above show how the different results of the Generative design process safety factor compare to the volume of the component. The taitanium starts with a minimun factor of aproximately 20 and after a few generations it shot to the 70 level then corrects it self back to achieve the minimun factor of safety which was at the level of 10s. The volume of titanium also reduces from 10,000 mm3 to around 5,000 mm3 .The stainless steel generation had a fair evolution of highs of 10 to 20 and as volume reduced it was able to achieve the minimum possible level of safety as well as aluminum.

Figure 18 Results produced by the GD exploration environment, volume in mm^3 vs mass in kg, solutions grouped according to the material

The generative design generators starts with maximum volume and material mass as shown in the graph with the first generation of each material. The generators then reduce both material in a linear manner as shown in the graph. Stainless steel starts at 0.5 kg and ends at 0.05 kg which is aproximately 10% of the original component this is a loss of 90% of material.The same is obsvered with titanum material and aluminum which is approximately 20% of original material. This shows that the generative design potential to reduce both mass and volume which directly corelate to cost and design manufacturing process while still maintaining functionality.

Figure 19 Results factor of cost produced by the GD exploration environment, cost in dollars vs total volume, solutions grouped according to the material

The results generated by the three studies that were done resulted in different ranges of cost of individual object/component to the overal component cost and all ceiling cost. The different material had different values titanium and steel being more expensive as indicated by the graph. Aluminium was the cheapest in production units ranging from $9 dollars (900ksh) to around $80 dollars (8000ksh). Titanium followed being cheaper than steel, it ranged from $80 dollars (8000ksh) dollars to 200 dollars. Stainless steel was more expensive production simulation the cost ranging from as low as $60 (6000ksh) dollars to around 300 dollars. Material affect the cost of production.

The figure below shows result of the GD process produced without a starting shape. Starting shapes give the generators a point of reference to begin with. The method of manufacturing are also influenced by the starting shapes of the study if any is introduced as shown in the figure. grouped by colour. The methods of manufacturing evidently show similarities in geometry produced by the algorithm.

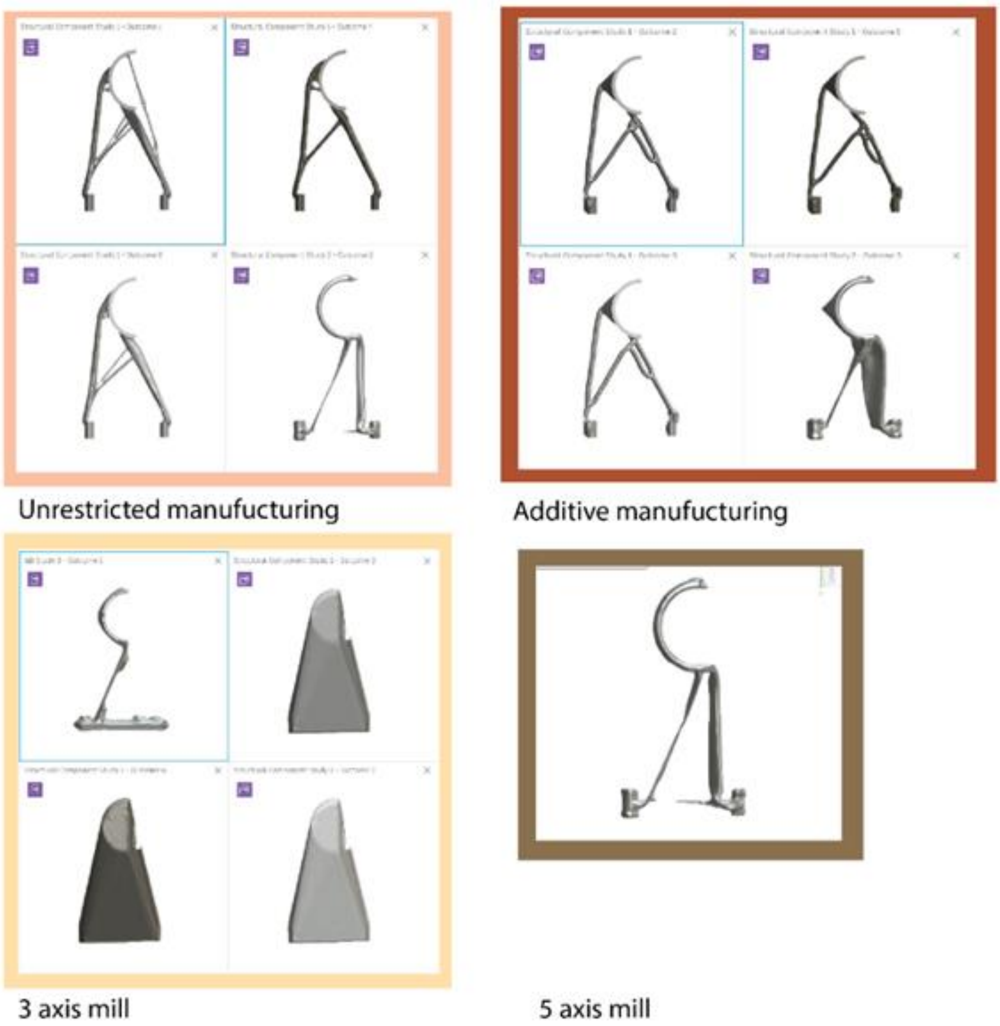

Figure 20 A selection of shapes produced by no starting shape analyses.

The constraints on production imposed by compliance, however, can be identified. Although global characteristics needed by the chosen process are confirmed in the results, the program can occasionally create local details that are not producible or have an impact on surface quality. This first generation produced some functional outcome on the unrestricted manufacturing process compared to 3 axis mill and 5 axis mill which the algorithm failed to produce appealing results. without a starting shape. In order to polish and refine the shapes produced by the GD, an editing phase is consequently implemented. At the editing phase the designer determines what parts are not needed or are for the study and re-run the generated component as the starting shape instead of starting from the begining.

The starting shape in this study dropped out since the result it was yielding were not meeting the targeted outcome. which has low mass, maximum stiffness, and low volume as much as possible. Some of the failed results are shown in the figure below.

Figure 21 Some results that failed with starting shape introduction

	OUTCOME 01	***OUTCOME 08***	***OUTCOME 04***	***OUTCOME 18***
				
Material	*Stainless steel*	*Aluminum*	*Titanium*	*Aluminum*
Manufacturing	*Unrestricted*	*Unrestricted*	*Unrestricted*	*Unrestricted*
Mass [kg]	*0.048*	*0.016*	*0.026*	*0.016*
Max Displacement [mm]	*0.047*	*0.166*	*0.079*	*0.126*

Table 6: Mechanical performance of a subset of GD-generated results.

A selection of the GD's results are showed in table 7 above. The results that were chosen to have structural behavior that complies with the restrictions listed in table 4. By giving the user the option to choose from a range of equally valid structural alternatives, the GD adds a fresh dimension. As a result, the user is better able to identify the solution that satisfies all of the design criteria, including those that were not explicitly stated in the GD study, by drawing on their own experience. Various aspects, such as ergonomics, aesthetics, manufacturability, and industrial know-how, may be significant and add to the value of the product depending on the application. To test the tool, the component from table 7, outcome 18 was chosen. After selection the outcome 18 is exported to mesh structure. The export process introduces some of the defects that had to be corrected for simulation and stress test purposes.

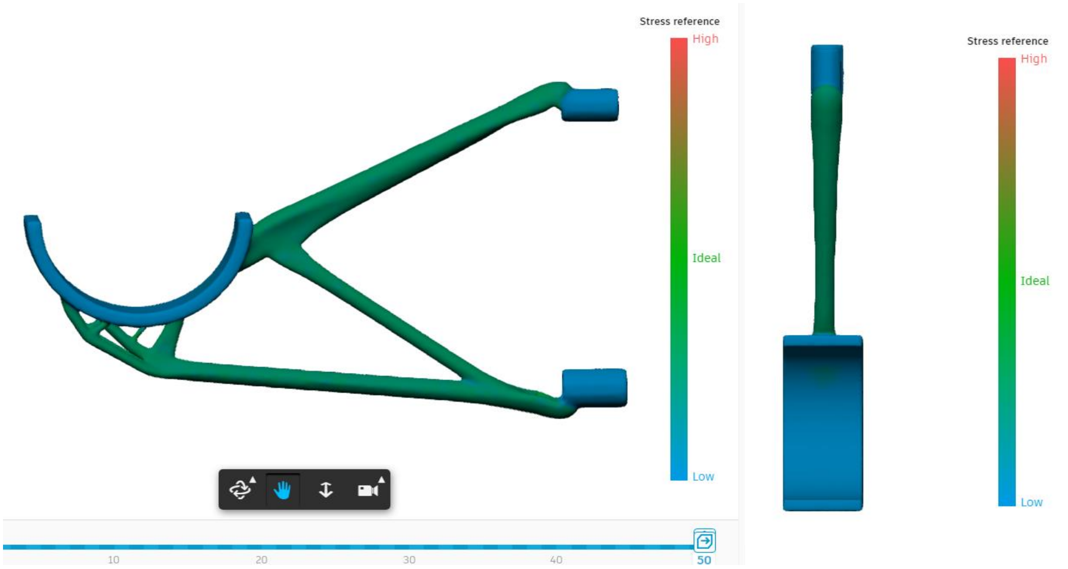

Figure 22 FE analyses performed within Fusion 360 on the final part: Stress test values.

As shown in figure 17. The stress and load test were performed by the GD process. As shown. The load handling regions of the curtain rod holder had an ideal to low stress under load: The bolts and adherence region of attachment to the wall, were also experiencing low to ideal stress under load. The generated structures also were performing ideally to the load and gravity exerted to them.

The generated component did not show extreme any stresses under the simulated load and gravity: All were. in ideal operation to low regions stress marked by blue and green color whereas there are no red to show extreme stress.

4.10 Conclusion

This chapter has looked at the analysis of both data collected from the field and data generated both by Generative design procedure. These sets of data gave the researcher insight on how both can be of use and thing to avoid when carrying out generative design. The generative design data brought to life other aspect such as cost comparison, mass and volume reduction.

5 CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter the conclusion from this study the potential of generative design in standardization of interior components around the topics of affordable housing project and the *Jua kali* sector. The conclusions were based on the purpose of the study and the results obtained. The recommendations were based on the conclusion and purpose of the study carried out.

5.2 Overview of the study

The study descriptive exploratory, descriptive comparative and qualitative study. The researcher adopted different techniques and methods to achieve objective of the study. Questionnaires and observation were conducted with different *jua kali* enterprises who were purposively selected for the study. The questionnaires and observation yielded results that were later used in the generative design study.

The researcher also had help from different Autodesk forums which were insightful for the solving of the generative design data. The data generated was further informed by the literature from different sources from publications to books.

The finding and recommendations described below are centered on the generative design data obtained and the Jua kali. The research question to be answered was:

"THE POTENTIAL OF GENERATIVE DESIGN IN STANDARDIZATION OF INTERIOR COMPONENTS FOR PRODUCTION OF AFFORDABLE HOUSING UNITS."

By answering this question, the study achieved the following objective:

I. It determines the technologies used in the Generative design industry and the methods used.
II. It identified processes of product standardization using generative design.
III. It established the design processes and procedures used in the informal sector *'jua kali'* in production of interior components.

5.3 Summary of the data

The data collected by the designer came in two categories one data collected from the *jua kali* enterprises and the data obtained by the generative design process. The data from the *jua kali* which included the time it takes to do the production, the cost of material used in the production process the amount of time it takes the enterprise to design and come up with the products.

The data from the generative design process included the data from the one identified component which was the curtain rod holder. The data was then fed into the generators in Fusion 360 which gave the researcher different options to generate the needed data. These constraints were the materials to be used in the manufacturing systems, the level of safety of the product and the load cases that will be exerted on the component which was the curtain rod holder in the researcher case. The study in fusion 360 yielded 32 results which 27 of them were completed by the generators after the four studies were done. Each study was yielding an average of 16 outcomes while others which had starting shapes were failing to produce expected outcomes or sometimes produced minimum yields of around 3 outcomes. All results generated are in the appendix 3. Each and every result in fusion 360 study had different generations for example is the outcome 18 in table 7 had 51 generations. The final outcome was the 51st generation while the others were the iteration it went through to get to final results. Each iteration was following the constraints put in place to come up with the final result.

5.4 Discussion on the potential of generative design on *jua kali* sector

The generative design world is new to many designers. At the start of the decade Computers were a farfetched dream that was unacceptable in the workplace. A few years later smartphones which are form the mainframe computers that existed in the mid-20th century now run the worlds day to day activities from communication, construction, manufacturing, health and agriculture among others. Today's world is run on the internet of thing (IoT) and cloud computing. The way researcher sought find out the link between the current situation in country's economy and affordable housing project. the potential it brings to the *jua kali* vendors/enterprises and if there is any potential of integration the generative which is part of the bigger cloud and machine learning technologies that exist.

The researcher broke down the study into three main groups which are on time it takes to produce products by the *jua kali* and generative design. Secondly in, material used by *jua kali* in the production and the potential generative design brings to the picture. Thirdly is on cost of production of goods and the way generative design can be utilized to minimize it.

5.4.1 The cost

The two fields that are generative design and *Jua kali* all have a common goal which is cost reduction. The *jua kali* enterprises can utilize Such technologies as generative design to come up with reasonable or targeted cost for efficient production which will aid in attainment of the government tenders in the affordable housing scheme. From the study as seen earlier in chapter 4 most enterprises strive to lower the overhead cost for maximum profitability of their enterprises.

5.4.2 The material

Through sustainable building design and material selection, sustainable construction and development considers the entire life cycle of buildings in order to minimize all negative on the built and natural environment. Throughout the cycle of a building components or structures, the materials chosen to have an impact on the environment. Building materials are employed from the construction stage to the operation stage, which includes building upkeep.

Material is the key element for the *Jua kali* enterprises to run. be it wood, metal, plastics, fabric upholstery among others. This then bring the necessity of them being very efficient in the production process. Each and every material counts. Generative design on the other hand tries as much as possible to minimize on the weight and volume of material used in the production as previously seen in chapter four. Generative design has a on' of components capability of reducing material up to 10% of its initial total volume and while mass and the still maintaining functionality and minimum safely factors. The affordable housing project also presented the opportunity for these enterprises to make components for the projects. and for these enterprises to be awarded these tenders they have to be very economical with how they use material as the government is trying to bring housing affordability to the common *wananchi* levels.

5.4.3 Time

Time is precious to any. individual any enterprise. as time lost is like a resource that you can't get back. Most of the enterprises from the study took long time to e come up with design." due to fear of making products only to realize. they have wasted their resources. Generative design and ritual production present opportunities for endless production and test without fear of resource wastage. The generative design had a production of 50 results which had generations averaging to 30. This brings the total iteration to 1500 per design. within a span of hours. The enterprises are presented with Immense opportunities with this virtual production processes which then enable them to save on time.

5.5 Limitations

Some limitations were identified by researcher while doing the research.

5.5.1 Participant's trust

The *Jua kali* enterprises sometimes were not giving the much-needed help which reduced the participant pool and sometimes the researcher had to change the participants. The participants were withholding information for fear of the researcher sharing with other enterprise's nullifying their competitive strength. This reduced the authenticity of the information collected.

5.5.2 Access to Software

Fusion 360 is an Autodesk product which has monthly subscription tag of 7000ksh or 50,000ksh annually. The researcher had to get an education access license to carry out the research. The educational license was only tied to education and research and not any commercial purposes The price tags for *jua kali* or the Kenyan developing economy can be steep at long run if they don't get any form of incentives.

5.5.3 Time and cost

The research had limited research time which narrowed down the study to a small niche. Generative Design can be used in different fields in Design ranging from spaces planning, product, graphics and fashion but the designer only had time to try and focus on one field which is interior components which does no bring the technology capabilities to picture.

RECOMMENDATIONS

Generative Design and Iterative design processes are among the spearheading technologies in the current design Engineering and Construction industry. These technologies are here to stay. Kenya as a developing nation should embrace these technologies for it to stride forward and sustain its needs. The main study areas were *Jua kali* and Affordable housing Program where the researcher focused to establish the link and how the technology can be used between the two areas. For these technologies to find their way to the different sectors the following are recommended:

- The resources should be made accessible and to the market and learning institutions to these technologies.
- Government should reduce tariffs and taxes on imported computer technologies to make it accessible to *jua kali* people.
- The government should set up fabrication plants that will ease production and make *Jua kali* productive rather than struggle more

- Designers should embrace there emerging technologies so that they can it down to the local market since few designers are informed on the upcoming Technologies.

5.6 The proposed *jua kali* generative design framework.

The field of generative design and jua kali are two fields that can benefit from one another strength. Jua kali can rely on benefit in areas like reducing time and material used. The man hours that go into jua kali are too much. From the research the two field: have different processes which can then be merged to form a coherent system. The target of the research was affordable housing, but the process can apply to other jua kali sectors.

The first stage ought to get the measurements and guides from AHP or any other sector involved in jua kali which are then translated into the working drawing so as to get or gain constraints to feed in to fast stage of generative design process, the jua kall first stage of doodling. and sketching is eliminated as generative design working drawing are more accurate and more presentable.

The record stages involves the generative stage idea so create objects with optimal material used and weights and volumes reduction. The generated ideas are then promoted to the stage where it can be transferred to production.

The generated idea is then transferred to jua kali production, line for cutting, molding from the generated ideas. The cutting and templating may vary due to material gauge and what is to be made

The cut template and pieces are then joined by the artisans to produce the desired shape or product. The joining method can vary from what is available.

After the joining the product can then receive the colour and finishes treatment and delivered to the client/customer

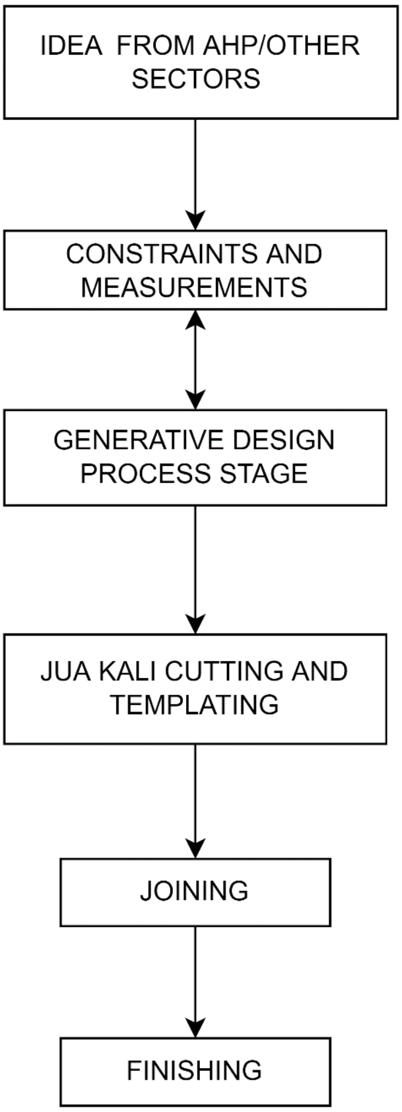

Figure 23 summary of proposed framework

5.7 Arears of further studies

The research could not exhaust all the aspects. of the generative design, affordable housing and *jua kali* at a go. From this study the three fields are broad and need further studies.

The researcher recommends the following key areas for further studies:

- A study of generative design cloud computing and artificial intelligence in terms of emerging technologies how they promise to revolutionize design and their impact to designers
- The impact of *Jua kali* on job creation in the Affordable Housing Scheme With the current state of the economy, which cannot support job creation for the entire population, particularly considering the negative effects of the Covid-19 pandemic,

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6 APPENDIX 01

DATA COLLECTION CHECKLIST

This is an academic research paper written in partial fulfillment of a Master of Arts in Design requirement. The study aims to assess the interior design components of affordable housing in Kenya, specifically windows, doors, and general floor layout.

COMPONENTS QUETIONNAIRE

This is an academic research paper witten in patial fulfillment of Masters of Arts in Design.The checklist aims to asses the interior design components in Affordable housing scheme produced by jua kali.

1. Component name.

   ____

2. What is the component measurements in mm ?

   Check all that apply.

   ☐ Length-
   ☐ Width-
   ☐ Height-

3. What is the component weight?

   Check all that apply.

   ☐ in kgs
   ☐ In grams

4. What material are used to make the Componet ?

   Mark only one oval.

   ◯ Material 01 -
   ◯ Material 02 -
   ◯ Material 03 -

5. What is the retail price Componet.

Mark only one oval.

	1	2	3	4	5	
Cheap	◯	◯	◯	◯	◯	Expensive.

MSME QUESTIONNAIRE.

This is an academic research paper in partial fulfillment of the requirement of an Master's Degree in Design. The research seeks to evaluate how generative design can be integrated in the jua kali sector and the affordable housing project in Kenya. There shall be absolute confidentiality on all information collected, hence anonymity in completing the questionnaire is offered as an option. The questionnaire is divided into two sections.

* Required

1. **What is the name of your Enterprise/bussiness.** *

   ____

2. **Gender** *

   Check all that apply.

   - [ ] Male
   - [ ] Female

3. **What is your age?** *

   Check all that apply.

   - [ ] Below 18
   - [ ] 19-24
   - [ ] 25-30
   - [ ] 31-36
   - [ ] above 36

4. **What is your highest level of Education?** *

   Check all that apply.

   - [ ] Primary School
   - [ ] Secondary school
   - [ ] College
   - [ ] University

5. **Do you know how to use computers and software?** *

Mark only one oval.

- ◯ Yes *Skip to question 6*
- ◯ No *Skip to question 8*

COMPUTER LITERACY SKILLS

This section tries to evaluate your knowledge and ability to use a computer and other Information and Communications Technology (ICT). It just covers your general view in computer literacy skills.

6. **Which computer software did you learn?**

____

7. **What is your level of proficiency of the software your learnt ?**

Mark only one oval.

	1	2	3	4	5	
starter	◯	◯	◯	◯	◯	pro

WORKSHOP QUESTIONS

This section tries to see what you as an entrepreneur /producer in the jua kali sector/MSMEs (micro, small and medium enterprises) and how you produce goods and services to wananchi.

8. **What does your business generally Focus on?**

Mark only one oval.

	1	2	3	4	5	
Single line product	◯	◯	◯	◯	◯	Many products

9. **What is the cost of materials used to make a single product?**

Mark only one oval.

- below -ksh 1000
- 1000/- to 2500/-
- 2500/- to 5000/-
- Above 5000/-

10. **How much of the production material goes to waste during production of goods?**

Mark only one oval.

	1	2	3	4	5	
little material						a lot of materials.

11. **How long does it take to design and make a product?**

Mark only one oval.

- A few days
- 1 week
- 2 Weeks
- 1 Month

12. **At what cost do you sell the product against the production cost to make profit ?**

Mark only one oval.

	1	2	3	4	5	
10% above production cost.						above 50% above production cost.

13. **Would consider integrating computers/generative design in your production process.**

Mark only one oval.

- ⬭ Yes
- ⬭ No
- ⬭ Maybe

7 APPENDIX 02

KOILA ANDREW MAITEI <koila.m.andrew@students.uonbi.ac.ke>

Thanks for using Fusion 360

1 message

Autodesk <information@autodeskcommunications.com> Sun, Oct 3, 2021 at 5:05 PM
Reply-To: no-reply@autodeskcommunications.com
To: Koila Maitei <koila.m.andrew@students.uonbi.ac.ke>

AUTODESK

Hi Koila Maitei,

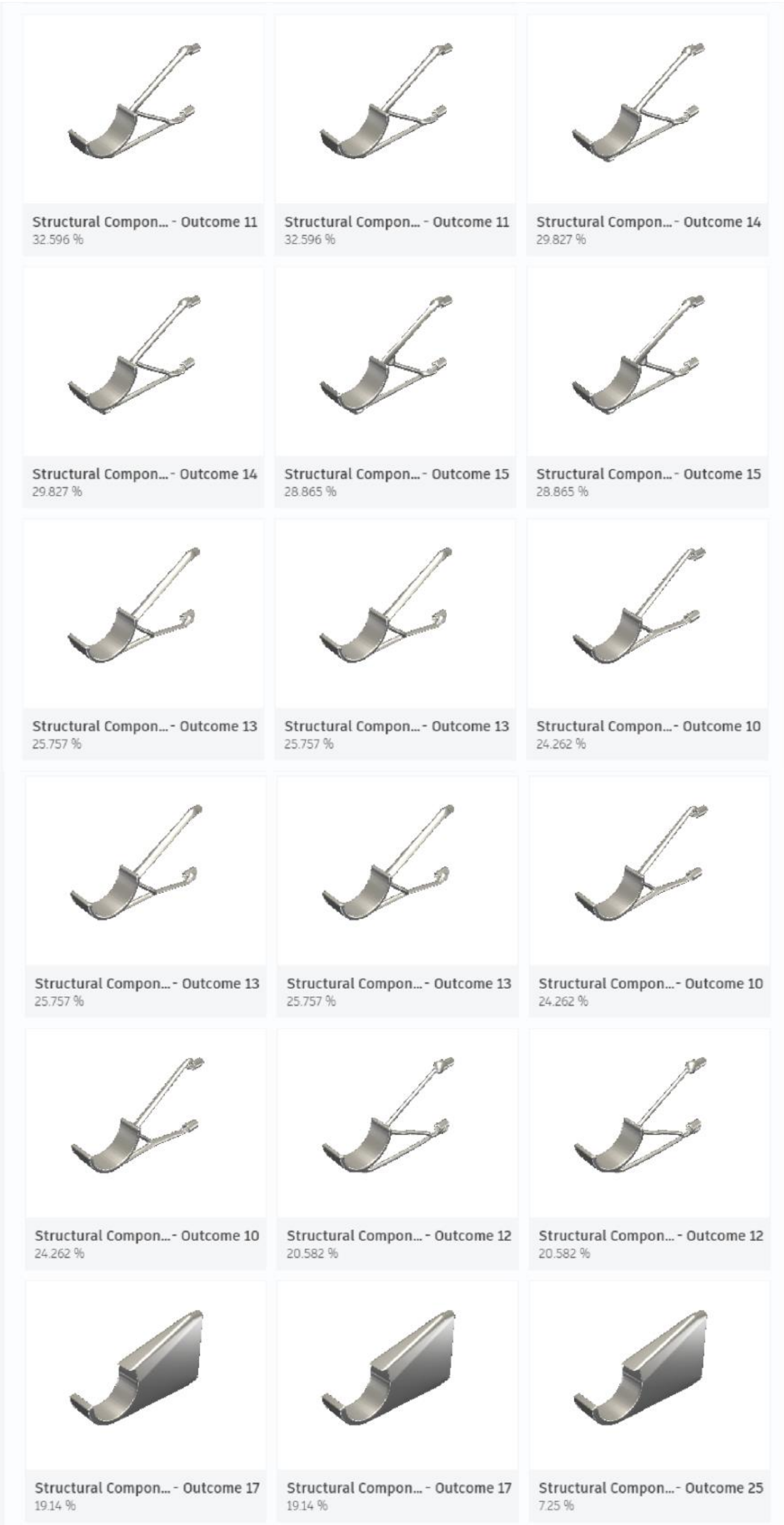
You're all set! Fusion 360 is yours to install and use until your educational access expires on August 27, 2022.

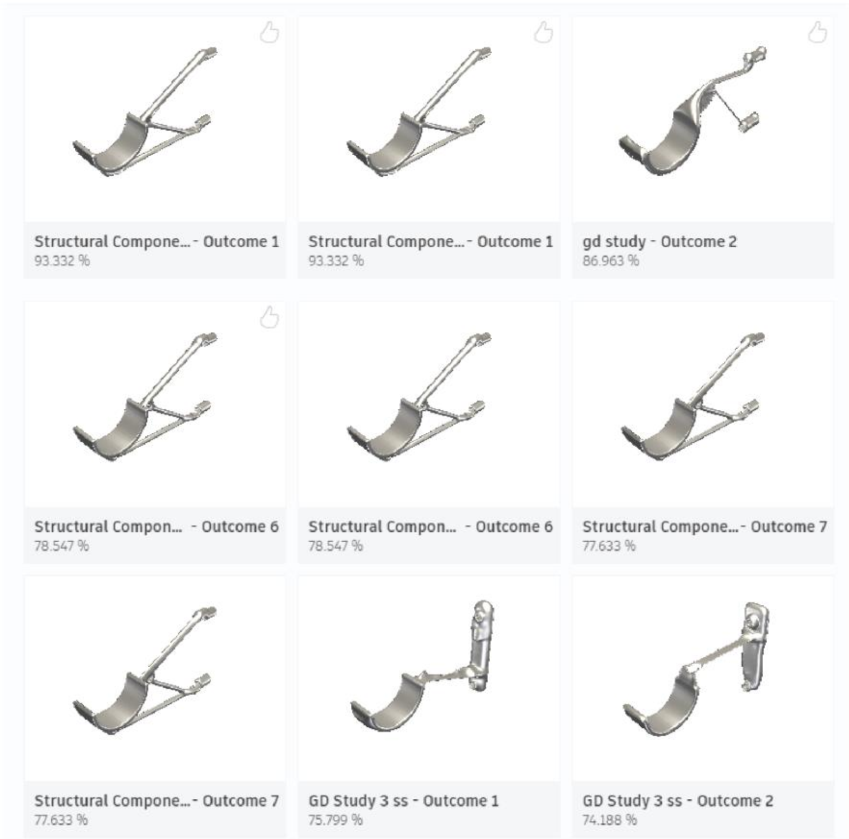
Best,
Autodesk

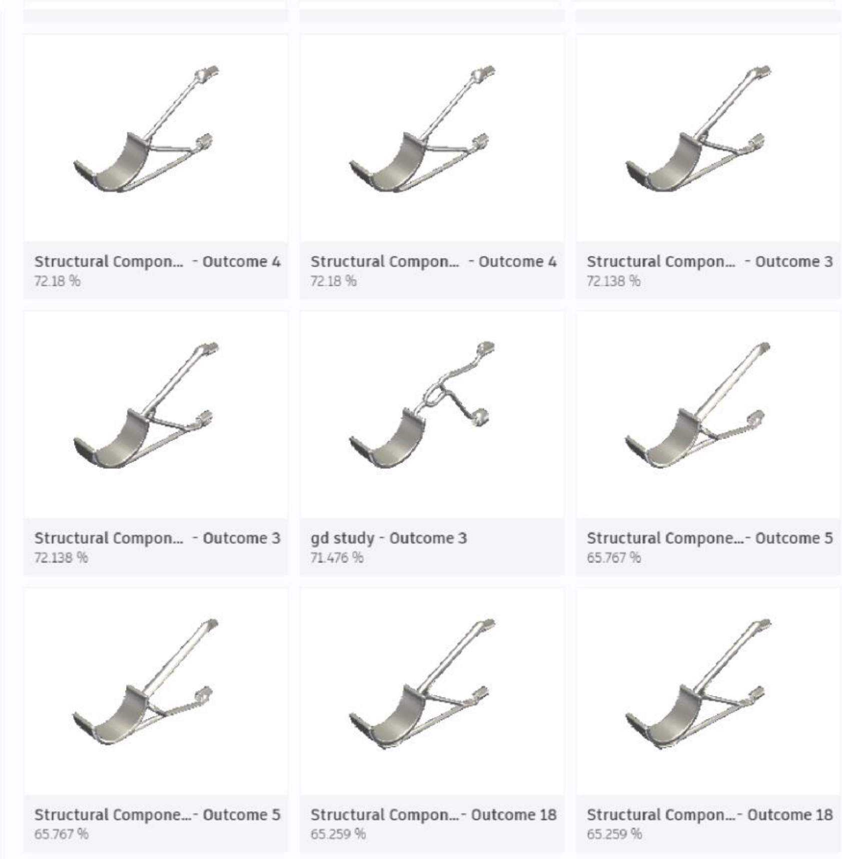
Autodesk, Inc. • 111 McInnis Parkway • San Rafael, CA 94903

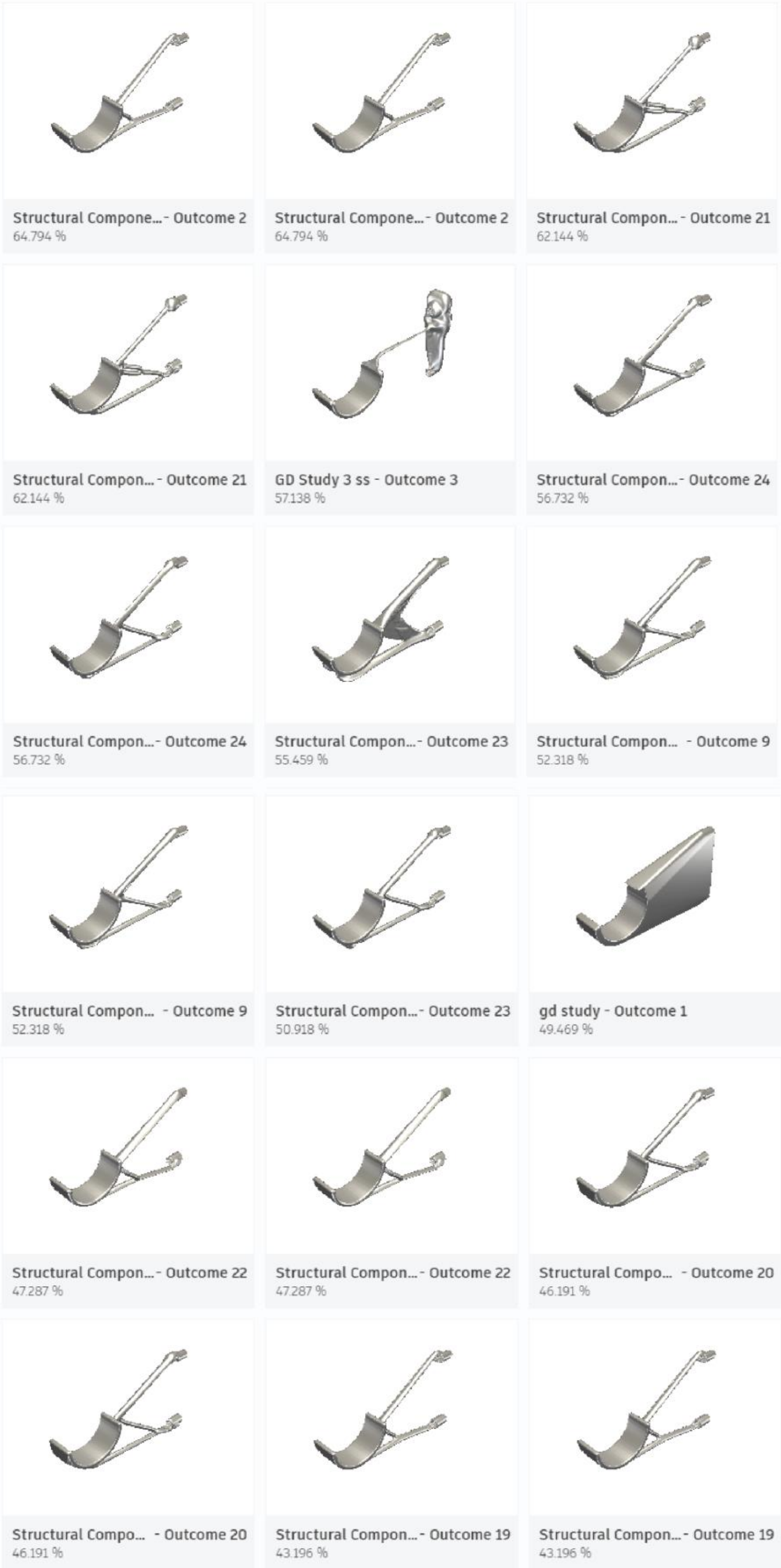
8 APPENDIX 03

THE GENERATIVE DESIGN RESULTS




Structural Compone...- Outcome 1
93.332 %
Structural Compone...- Outcome 1
93.332 %
gd study - Outcome 2
86.963 %
Structural Compon... - Outcome 6
78.547 %
Structural Compon... - Outcome 6
78.547 %
Structural Compone...- Outcome 7
77.633 %
Structural Compone...- Outcome 7
77.633 %
GD Study 3 ss - Outcome 1
75.799 %
GD Study 3 ss - Outcome 2
74.188 %


Structural Compon... - Outcome 4
72.18 %
Structural Compon... - Outcome 4
72.18 %
Structural Compon... - Outcome 3
72.138 %
Structural Compon... - Outcome 3
72.138 %
gd study - Outcome 3
71.476 %
Structural Compone...- Outcome 5
65.767 %
Structural Compone...- Outcome 5
65.767 %
Structural Compon...- Outcome 18
65.259 %
Structural Compon...- Outcome 18
65.259 %


Structural Compone...- Outcome 2
64.794 %
Structural Compone...- Outcome 2
64.794 %
Structural Compon... - Outcome 21
62.144 %
Structural Compon... - Outcome 21
62.144 %
GD Study 3 ss - Outcome 3
57.138 %
Structural Compon...- Outcome 24
56.732 %
Structural Compon...- Outcome 24
56.732 %
Structural Compon...- Outcome 23
55.459 %
Structural Compon... - Outcome 9
52.318 %
Structural Compon... - Outcome 9
52.318 %
Structural Compon...- Outcome 23
50.918 %
gd study - Outcome 1
49.469 %
Structural Compon...- Outcome 22
47.287 %
Structural Compon...- Outcome 22
47.287 %
Structural Compo... - Outcome 20
46.191 %
Structural Compo... - Outcome 20
46.191 %
Structural Compon...- Outcome 19
43.196 %
Structural Compon...- Outcome 19
43.196 %