ERGONOMIC REDESIGN OF SEWING WORKSTATION FOR GARMENTS MANUFACTURING: A CASE STUDY OF RIVATEX EAST AFRICA LIMITED, ELDORET, KENYA

BY

ABDALLA E. A. ESMAEEL

A THESIS SUBMITTED TO THE SCHOOL OF ENGINEERING, DEPARTMENT OF MANUFACTURING, INDUSTRIAL AND TEXTILE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DOCTOR OF PHILOSOPHY DEGREE IN INDUSTRIAL ENGINEERING

MOI UNIVERSITY

2026

DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or Moi University.

Signed: ___________________________________ Date: ____________________

Abdalla Esmaeel.

PHD/IE/5675/22.

Declaration by the Supervisors.

This thesis has been submitted for examination with our approval as the university supervisors.

Signed: ___________________________________ Date: ____________________

Prof. Eng. Diana Madara.

Department of Manufacturing, Industrial and Textile Engineering, School of Engineering, Moi University, Eldoret, Kenya.

Signed: ___________________________________ Date: ____________________

Prof. Eng. S. P. Ayodeji.

Department of Industrial and Production Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure, Nigeria.

Signed: ___________________________________ Date: ____________________

Dr. Jerry Ochola.

Department of Manufacturing, Industrial and Textile Engineering, School of Engineering, Moi University, Eldoret, Kenya.

DEDICATION

To

The Soul of my Beloved Mother

My Dear Father

My Dear Sisters and Brothers

My Dear Wife

My Dear Daughter

My Dear Friends

My Dear Supervisors Prof. Diana Madara, Prof. S. P. Ayodeji, and Dr. Jerry Ochola.

ACKNOWLEDGMENT

First, I am truly grateful to the most powerful and gracious Almighty Allah, who has given me the strength, wisdom, patience, and guidance to reach this point and successfully complete my research studies. I would also like to extend my sincere thanks and appreciation to my first supervisor, Professor Eng. Diana S. Madara, for her genuine interest in my research and her invaluable feedback that greatly improved my work; to my second supervisor, Professor Eng. S. P. Ayodeji, for his expertise in design details; and to my third supervisor, Dr. Jerry Ochola, for his excellent input on the research objectives and valuable contributions to my writing methods. The completion of this research would not have been possible without their guidance and support. May Allah/God bless them forever. I wish to thank the REAL factory where I conducted my research; their commitment to creating a safe environment and quality products made my research enjoyable and educational, as well as all the workers involved in the anthropometric measurements. I also wish to thank my assistant, Monica Achieng, for her help with the measurements of female subjects in the research. Additionally, I would like to express my appreciation to several individuals whose efforts have significantly advanced and marked my academic career. Sincere gratitude also goes to ACEII-PTRE, SPREE, and RUFORUM for fully funding this research. Without their support, I would not have been able to achieve everything I have. I genuinely appreciate the postgraduate lecturing staff of the School of Engineering at Moi University for their unwavering support in my education. My gratitude also extends to my colleagues and friends, who have been a constant source of support. Finally, I would like to convey my heartfelt gratitude to my beloved wife and other family members for their sacrifices, support, and encouragement in successfully completing this thesis.

Abdalla Esmaeel ✍

ABSTRACT

Worldwide, the design of a workstation in many garment industries is usually done with minimal consideration of anthropometric data. This may cause hazards and reduce work efficiency as a result of sitting for long periods of time in uncomfortable positions. Ergonomically redesigned workstations are known to reduce Musculoskeletal Disorders (MSDs) and improve the motivation of the garment workers in the workstation environment. The main objective of this study was to redesign an ergonomic sewing workstations for garment manufacturing using selected anthropometric data collected at Rivatex East Africa Limited (REAL), Eldoret, Kenya. The specific objectives were: to assess work-related risks and hazards for garments-making workers at sewing workstations; to determine the relevant anthropometric dimensions from garments-making workers for a sewing workstation; to redesign a sewing workstation for garments-making workers; to simulate the redesigned sewing workstation; to optimize the redesigned workstation for garments-making workers at sewing operations; and to fabricate the redesigned sewing workstation. Rapid Entire Body Analysis (REBA) method was used to assess the ergonomic risk of the existing workstation. The sample size of 100 was determined. Eleven anthropometric measurements were taken from workers using ISO 7250-1:2017 and compared using one-way analysis of variance (ANOVA). Using the anthropometric data, a redesigned sewing workstation model was proposed. The model was analyzed using Computer Aided Three-Dimensional Interactive Application (CATIA V5) software based on Rapid Upper Limb Analysis (RULA). The model was simulated using SolidWorks 2024 software based on Finite Element Analysis (FEA). Aluminum alloy 1060 was selected for FEA. The FEA criteria included: stress, displacement, strain and Factor of Safety (FOS). The model was optimised using design study. The model was then fabricated in accordance with the necessary manufacturing process. ANOVA tests results failed to reject the null hypothesis in the data sets ($P > 0.05$), thus, there was no significant difference between the anthropometric data. The recommended dimensions for workstations are redesigned, significantly reducing the mismatches between workstation dimensions to the relevant body dimensions. Analysis results of the workers' posture for the existing sewing workstation had a final REBA score of 5, implying existence of medium ergonomic risk, hence, changes were necessary. The proposed sewing workstation had a final RULA score of 1, meaning that the ergonomic risk is negligible. The FEA results showed that the maximum stress was 7.175E-01 MPa and did not exceed the yield strength; the maximum deformation was 0.03209 mm, which was below the assigned safety level; the maximum strain was 6.258E-06 and within the range for the material; and the minimum FOS distribution was 3 implying that the model was within the safety range limits. The optimisation results showed that the optimal dimension of the model was 416.5 mm for seat height, 457 mm for seat depth and 472.8 mm for seat width; the optimal stress of the model was 2.662E+01 MPa; and the optimal mass of the model was 19865.24 g. In conclusion, the dimensions of the redesigned sewing workstation was recommended. The proposed redesigned workstation should be suitable for all garment workers in Kenya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TERMS AND DEFINITION

For this thesis, the following terms and definitions are applicable:

Anthropometry: dimensions of the human body and how these are measured. It covers the size and proportions of people, the length and range of movement of their limbs, head and trunk.

Biomechanics: The application of physics to the analysis of body posture and human movement. It deals with the levers and arches of the skeletal system and the forces applied to them by the muscles and gravity.

End-user: A person who uses a product rather than one who makes or sells, especially a person who uses a product connected with computers.

Ergonomics: The study of working conditions, specifically the design of equipment and workstation furniture, to help people, work more professionally.

Occupational ergonomics: Ergonomics is applied at work to the design of the workstation, equipment, tasks and work organisations.

Fatigue: A state of impairment that can include physical and mental elements, associated with lowered alertness and reduced performance.

Harm: Physical injury or damage to the health.

Hazard: Potential source of harm.

Injury: Damage to the body caused by exposure to a hazard.

Risk: Combination of the probability of occurrence of harm and the severity of that harm.

Risk analysis: Combination of the specification of work/task description, hazard identification and risk estimation.

Musculoskeletal disorders: They are conditions that affect the body's muscles, joints, ligaments, and nerves.

Risk assessment: The process used to determine the likelihood of people being exposed to injury, illness or disease in any situation identified during the hazard identification process; and, the severity of the illness, injury or disease.

Risk estimation: Defining the likely severity of harm and probability of its occurrence.

Risk evaluation: Judgment on the basic of successive risk analysis of whether the risk reduction objectives have been achieved.

Standards: These are issued by the standard setting body in each country and provide guidelines relating to the design, operation and maintenance of equipment and systems. All standards have a specific number and date.

Von Mises stress: It is a number that gives an overall idea about the state of stresses at location.

Work space: It is the volume of space allocated to one or more persons in the work system to complete a work task.

Workstation: It is a place where the workers perform their tasks such as office, factory, etc.

ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used in this thesis apply:

AHDEL: American Heritage Dictionary of the English Language.

ANOVA: Analysis of Variance.

BC: Before Christ.

BIFMA: Business and Institutional Furniture Manufacture's Association.

BMI: Body Mass Index.

BOM: Bill of Material.

BPL: Buttock popliteal length.

CAD: Computer Aided Design.

CATIA: Computer Aided Three-dimensional Interactive Application.

CNC: Computer Numerical Controlled.

CSM: Concept Scoring Method.

CTS: Carpal Tunnel Syndrome.

DELMIA: Digital Enterprise Lean Manufacturing Interactive Application.

DHM: Digital Human Model.

DPM: Digital Process for Manufacture.

3DSSPP: Three Dimensional Static Strength Prediction Program.

EH: Elbow Height.

EMG: Electromyography.

FEA: Finite Element Analysis.

FJM: Fit the Job to the Man.

FMJ: Fit the Man to the Job.

FOS: Factor of Safety.

HAAM: Human Activity Analysis Model.

HB: Hip Breadth.

HBM: Human Builder Model.

HDM: Human Digital Model.

HFS: Human Factors Society.

HMEM: Human Measurement Editor Model.

HPAM: Human Posture Analysis Model.

IBM: International Business Machines.

IEA: International Ergonomics Association.

KEBS: Kenya Bureau of Standards.

MSDs: Musculoskeletal Disorders.

MSP: Musculoskeletal Pain.

NACOSTI: National Commission for Science, Technology and Innovation.

NASA: National Aeronautics and Space Administration.

NIOSH: National Institute for Occupation Safety and Health.

OHS: Occupational Health and Safety.

OSHA: Occupational Safety and Health Administration.

OWAS: Ovoko Working Analysis System.

PH: Popliteal Height.

PPE: Personal Protective Equipment.

PVC: Polyvinyl Chloride.

RAMSIS: Realistic Anthropological Mathematical System for Interior Simulation.

REAL: Rivatex East Africa Limited.

REBA: Rapid Entire Body Assessment.

RPA: Rapid Postural Assessment.

RULA: Rapid Upper Limb Assessment.

RWI: Recommended Weight Limit.

SAMMIE: System for Aiding Man-Machine Interactive Evaluation.

SD: Seat Depth.

SH: Seat Height.

SME: Small and Medium-Sized Enterprise.

SW: Seat Width

TH: Table Height.

UN: United Nations.

USD: United States Dollar.

WRMSDs: Work-Related Musculoskeletal Disorders.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This first chapter of the current thesis provides the general background information for this study. It also outlines the research problem, justification the study, and details the research objectives and scope. Following this, the purpose and significance of the study are presented.

1.1 Background of the Study

Worldwide, the design of workstations in many garment industries is often done with minimal consideration. This oversight can lead to hazards and decreased work efficiency due to prolonged periods of sitting in uncomfortable positions. Ergonomically redesigned workstations are known to reduce musculoskeletal disorders (MSDs) and enhance the motivation of garment workers in their work environment. The main objective of this study was to redesign ergonomic workstations for garment manufacturing using selected anthropometric data collected at Rivets East Africa Limited (REAL). The REAL factory is a vertically integrated textile plant, encompassing spinning, weaving, wet processing, and garment operations. This factory is located in Eldoret, Uasin Gishu County, Kenya (Musau, 2018 and East & Limited, 2020). See Appendix I for the research area map.

In many developing countries, export-led industrial expansion has been ignited, particularly through the garment industry (Natsuda et al., 2010). The garment sector plays a crucial role in the economic development processes of these nations (Kaya, 2015). The early industrialisation of both industrialised and developing nations was characterised by the garment and textile industries, which required only a modest degree of production technology and a sufficient amount of inexpensive labor (Yang &

Zhong, 1998 and Wang et al., 2010). The garment sector, primarily composed of small and medium-sized enterprises (SME), is one that demands a significant amount of manual labor. Further, the occupational health and safety programs in developing countries typically focus on large-scale organisations (Ahmad et al., 2021). The most frequent occupational health risk among workers is musculoskeletal pain (MSP), and it is unclear what drives their health-seeking behavior (Akinpelu et al., 2016). Likewise, the most common issue is that nearly every worker experiences musculoskeletal complaints due to non-adjustable and non-ergonomic work desks and chairs (Kaya, 2015; Lindh et al., 1991). According to Zeynep et al., (2019), work-related musculoskeletal disorders (WRMSDs) are among the most prevalent health issues affecting workers at their workstations. Operators of sewing machines in the fashion industry are exposed to dangers and discomfort that accumulate over time (Okareh et al., 2021). Moreover, the majority of clothing manufacturing still occurs in cramped, unfriendly environments where little attention is paid to the layout and conditions of the workstation, putting workers at risk (Sohn et al., 2021).

According to Herbert et al., (2001), thirty-six (36) garment workers involved in the spooling process were examined to assess the impact of an ergonomics intervention program on the frequency and severity of upper extremity symptoms. Additionally, hazardous technologies have been introduced into the industry, resulting in a high accident rate, occupational diseases, and unpleasant working conditions (Malik et al., 2010). Research by Ansari et al., (2014) indicates that most small-scale manufacturing is still performed manually, and the issues of WRMSDs and injuries in various body sites are of utmost priority. In the garment industry, for instance, many sewing machine workers are subjected to conditions that jeopardise their health atting. Previous research by Patil et al., (2017) indicates that workers operating machines face a significantly higher risk of muscle pain and injury compared to those in other occupations. Research by the mendeley support team & shih, (2010) noted that uncomfortable body positions of sewing machine operators can lead to an increase in MSDs complaints, which in turn affects operators' productivity.

Research by many scholars, including Biadgo et al., (2021); Norhidayah et al., (2016); Okareh et al., (2021); Parimalam et al., (2006) has observed that poorly designed workstations, inappropriate workstation furniture, inadequate ventilation, poor lighting, excessive noise, and insufficient protection from hazardous chemicals, dust, and poor housekeeping, along with a lack of personal protective equipment (PPE), are just a few examples of these hazards. These factors can increase workers' vulnerability to pain and occupational diseases. Given the rising proportion of manual activities in production processes, there is a persistent risk of MSDs and work-related injuries. Consequently, the risk of these issues is heightened by the trend toward an aging workforce (Greggi et al., 2024). Ergonomics is the study of the interaction between humans and machines, as well as the factors influencing this interaction. It is a broad science encompassing various working conditions that impact workers' comfort and health. Therefore, it examines humans in relation to their work environment. Ergonomics primarily focuses on individuals and their interactions with products, equipment, facilities, and the environments utilized in workplaces. European legislation is advocating for enhanced working conditions to mitigate health risks for workers, which are often linked to the ergonomic design of workstations (Tee et al., 2017).

According to Caputo et al., (2006), the goal of industry is to apply ergonomic criteria to minimize accidents at the workstation and enhance productivity. Additionally, there are various methods for incorporating ergonomics into workstation design using anthropometric measurements. Research by Mousumi, (2015) indicates that the term "anthropometry" encompasses different types of measurements that accurately describe the human form. Furthermore, anthropometry is the science of measuring the human body, which helps to elucidate the complexities of the human form and its interaction with the work environment (Igbokwe et al., 2019). Further, an anthropometric measurement involves the collection of physical characteristics of the human body that are relevant to ergonomic design, clothing size, physical anthropology, tool redesign, consumer product design, and equipment, among other fields (Fahad & Althuwaini, 2025). These characteristics include size, body shape, strength in both dynamic and static conditions, and the capacity to perform tasks. When anthropometric measurements are considered for design, they help reduce low back pain, improve comfort levels, decrease MSDs, enhance productivity, and increase user performance as well (Mahantesh et al., 2023).

For designing any product, engineers must rely on scientific anthropometric data to create spaces that accommodate the largest number of people. Otherwise, the result may be a non-ergonomically designed product. This can also lead to biomechanical stresses and increase the risk of cumulative trauma and carpal tunnel syndrome for workers. Research by Mousumi, (2015) recommended that for the design and implementation of safe tools, it is essential to utilize anthropometric data that can impact job performance quality and productivity, as well as the safety and health of workers. To minimize poor anthropometric correspondence between the workstation product and users, the designer and engineer must use validated, accurate, and updated anthropometric measurements (Leilanie, 2004). Additionally, to enhance usability and reduce negative effects on the user, creating a work environment that is more comfortable, safe, and friendly enables higher performance and fosters a productive working atmosphere (Del, 2007).

All products, including clothing, consumer goods, and systems of products such as office workstations, vehicles, and PPE, need to be tailored to users to enhance product usage throughout a person's lifetime (Nadadur & Parkinson, 2013). According to Eladly et al., (2020), in the case of ergonomic design for workstations, it is crucial to achieve a balance between the workstation's dimensions and the worker's anthropometric measurements to reflect the man-machine relationship. Therefore, this study aims to establish anthropometric data for garment workers at the sewing workstation to improve their physical responses and overall performance.

1.2 Statement of the Problem

As the global workstation environment becomes increasingly dynamic, organizations and businesses are compelled to continuously seek the best strategies for planning and managing innovation through new methods and paradigms that effectively cater to both new and existing markets with innovative products and services (Koirala, 2022). Kinnunen & Liira, (2014) noted that working conditions are influenced by globalization and changes in the work environment due to new technologies and practices. Attwood et al., (2003) discussed that work-related injuries, such as back injuries and carpal tunnel syndrome, are the most prevalent, costly, and preventable workstation injuries. The Occupational Safety and Health Administration (OSHA) estimates that over 647,000 workdays are lost annually (Ankara, 2022; Dergisi & Sciences, 2014a).

In developed countries, ergonomics is applied across various fields, including health care, education, the service sector, agriculture, industry, and production (Kinnunen & Liira, 2014; Lundgren et al., 2013; Patil et al., 2017; Eugene, 2017; Li et al., 2019). However, developing countries still lag significantly in implementing ergonomic principles in the workplace (Jilcha & Kitaw, 2016). Previous study by Shah et al., (2016) have shown that the garment manufacturing industry is highly labor-intensive, particularly in developing nations. Often, workers must operate under adverse conditions, typically enduring long hours with only one lunch break during the day. These laborers are seldom provided with suitable workstations, and inadequate social infrastructure further increases the risk of discomfort and illness. Kahare, (2014) notes that many researchers in Kenya have, over the years, demonstrated little interest in the subject of ergonomic principles. In a developing country like Kenya, sewing garment manufacturing plays an important role in overall economic development (Gok, 2015; Musau, 2018). It is essential to consider the measurement of human body dimensions for workers to decrease physical workload, enhance performance efficacy, and improve health conditions as well (Manivel, 2019; Hsue et al., 2025).

Many researchers, such as Nadadur & Parkinson, (2013); Halpern & Dawson, (1997) and; Li et al., (1995), have shown that the repetitive nature of sewing tasks performed in uncomfortable postures, due to inappropriately designed tools, may be a risk factor contributing to the significant incidence of MSDs in the sewing industry. Sealetsa & Thatcher, (2011) found that the design of the sewing machine and workstation layout, despite being adjustable, did not align with the anthropometric measurements of the workers. Consequently, the operators were unable to make appropriate adjustments to the workstation during their work activities. An existing work by Kalınkara et al., (2011) showed that over 55.5% of workers face issues stemming from their working environment and equipment. Previous research by Talapatra & Mohsin, (2020) confirmed that the workstation in garment manufacturing is associated with various risks and hazards that negatively impact both worker health and the environment. Consequently, ergonomic evaluations often occur after physical models have been developed and typically take place late in the design phase (Soana et al., 2025). This is due to the low priority given to meeting established ergonomic standards, which can lead to costly and time-consuming revisions and/or a decline in the quality of the final product. Integrating ergonomic principles into workstation design for garment manufacturing could represent a significant advancement.

The workstation layout is a significant factor contributing to movement instability when transferring parts and/or products that workers may hold, lift, pull, or push. Furthermore, workers in the garment industry engage in sewing services due to the nature of their job, and the poor design of physical workstations has likely led to physical complaints and health-related issues (Mousumi, 2015). Ergonomic principles are not well recognized among companies, and their importance is not widely disseminated. Additionally, implementing ergonomic improvements is part of a company's strategy to integrate health and safety with ergonomic principles in workstation design. Thus, combining anthropometric data with ergonomic principles can enhance work pace, workload, and overall efficiency. This may positively impact well-being and safety while empowering workers by providing better conditions, simplifying processes, and equipping them with the tools to make a difference.

The design of workstations in the garment industry often lacks sufficient consideration of anthropometric data. There exists a mismatch between workstation dimensions and workers' anthropometric characteristics. This can lead to hazards and negatively impact working efficiency due to prolonged sitting in awkward positions. Ergonomically designed workstations are known to reduce hazards and enhance the mindfulness and attentiveness of workers in the workstation environment. This study focused on the ergonomic redesign of workstations to bridge the gaps between sewing workstation dimensions and workers' anthropometric measurements, aiming to improve both worker performance and well-being.

1.3 Justification of the Study

To be effective and efficient, the garment industry needs to continuously identify work-related problems and, more importantly, implement solutions to reduce WRMSD in situations where these issues arise. Additionally, ergonomic research on workstation design aims to enhance work performance (both in quality and quantity) (Of, Alberta, 2021) to:

1. Minimize the physical stress and workload of the individual worker;
2. Reduce hazards by modifying the design of the work environment to align with the abilities of the workers;
3. Facilitate job performance, i.e., ensuring seamless information exchange within the workstation environment;
4. Minimize physical constraints;
5. Ensure occupational health and safety (OHS);
6. Achieve user-friendly workstation design;
7. Enhance worker performance and satisfaction;
8. Reduce long-term discomfort in workers;
9. Improve the production process;
10. Refine the design of the workstation to promote physical health;
11. Alternate between sitting and standing postures while performing a job;
12. Boost workers' performance and the productivity index in workstations;
13. Decrease Work-Related Musculoskeletal Disorders (WRMSDs);
14. Enhance overall productivity.

This study aims to enhance the human-machine interface for garment-making workers and their workstation environment. This will lead to significant improvements in work conditions and ergonomic practices that focus on reducing work stress, health issues, and applying ergonomic principles. The findings of this study should contribute to a better understanding of the working conditions associated with sewing activities in the garment manufacturing industry. These insights could aid in designing ergonomic integrations that minimize miscalculated symptoms for garment workers and enhance job quality, ultimately boosting work productivity as well.

1.4 Objectives of the Study

Basically, the present study was conducted by the following objectives:

1.4.1 Main Objective

The main objective of the study was to redesign an ergonomic sewing workstations for garments manufacturing based on the selected anthropometric data at REAL, Eldoret, Kenya.

1.4.2 Specific Objectives

The lists of the specific objectives that need to be achieved for the successful achievement of this present research were to:

1. Assess work related risks and hazards for garments-making workers at sewing workstation.
2. Determine the relevant anthropometric dimensions from garments-making workers at sewing workstation.
3. Redesign a workstation for garments-making workers at sewing operations.
4. Simulate the redesign of workstation for garments-making workers at sewing operation.

5. Optimise the redesign of workstation for garments-making workers at sewing operation.
6. Fabricate the redesign of workstation for garments-making workers at sewing operation.

1.5 Scope of the Study

The scope of the study is carefully aligned with the specific objectives that the thesis aims to achieve. This study utilized standard procedures for anthropometric measurements from garment-making workers at a sewing workstation in REAL, Eldoret, Kenya. It will focus on assessing, determining, redesigning, simulating, optimizing, and fabricating a workstation redesign based on the selected anthropometric measurements collected from workers. This study will concentrate on the optimal ergonomic sewing workstation redesign that accommodates the physical dimensions of workers according to engineering ergonomic criteria.

1.6 Significance of the Study

Ergonomics principles can significantly impact any organisation, offering numerous benefits when applied. These include reducing ergonomic risks and enhancing safety at the sewing workstation, lowering costs by minimising worker injuries, and boosting productivity through a better-designed sewing workstation that ensures good posture, fewer motions, and less exertion for workers. Additionally, improved quality results from addressing poor ergonomics, which can lead to fatigued and frustrated workers who may not perform at their best. When workers do not experience discomfort and fatigue during their daily activities, their overall performance improves.

This can lead to reduced absenteeism, enhanced morale, and improved worker involvement, as well as healthier human performance due to a safe and health-conscious culture established in society. The success of the study will ultimately benefit garment workers by creating an anthropometric database for workstations in sewing operations at REAL, Eldoret, Kenya.

The rationale for selecting the subject, which focuses on creating an anthropometric database alongside integrated ergonomics principles, lies in its ″novel″ nature, aiming to explore and study this area. There is confidence that significant benefits can arise from a broader incorporation of ergonomics principles in the improvement plans of garment companies. The availability of ergonomic workstation furniture will yield advantages for garment manufacturing in Kenya. Garment companies are obligated to provide sufficient facilities and infrastructure to support workers' activities.

This research aims to utilize anthropometric measurements as a design tool for innovative ergonomic sewing workstation furniture suitable for garment workers in Kenya. This study will employ anthropometry (a branch of human factors engineering/ergonomics) as one of the research tools for redesigning, simulating, optimizing, and fabricating sewing workstations to be used by garment-making workers. It seeks to improve the physical posture, comfort, and overall performance of garment workers.

This study aims to reduce, in the long run, the discomfort experienced by workers and WRMSDs during prolonged sitting in sewing workstation environments. The research will provide a database for future studies and is potentially beneficial to similar sewing workstations, regardless of their geographical location. This study will hopefully serve as a reference point for scholars and researchers in the future within this novel field.

1.7 Purpose of the Study

The purpose of this study was to redesign an ergonomic sewing workstation for garment manufacturing, based on selected anthropometric data from the REAL factory in Eldest, Kenya. This redesign aims to improve the alignment between workstation dimensions and the workers' anthropometric characteristics. To reduce musculoskeletal disorders (MSDs), operators have reported the need for more favorable posture angles to enhance productivity rates. This research examines the relationships between the anthropometric data of sewing workers to optimize their performance. The study recommends utilizing anthropometric data in workstation redesigns for Kenyan sewing workers to improve their health and productivity in the long term.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter provides an overview of the key literature relevant to the present research. It is organised into seven sections: (1) Assessing work-related risks and hazards: ergonomic risk factors and methods for evaluating workstation ergonomics; (2) Determining anthropometric measurements: an overview of anthropometry, a brief history, applications of anthropometric data, types of anthropometric measurements, anthropometric body dimensions, the importance of integrating anthropometric data in workstation design, and anthropometric considerations for the workstation; (3) Designing an ergonomic workstation: an overview of ergonomics science, a brief history of ergonomics, benefits of an ergonomics process, the importance of ergonomics, workstation problems and ergonomic responses, ergonomics within constrained design realities, designers as users of ergonomics information, challenges in contributing from an ergonomics perspective, the significance of integrating ergonomics in design, engineering and general design considerations, applications of ergonomics, ergonomic impacts on worker performance, ergonomics at industrial workstations, industrial workstation design, the evolution of ergonomics in workstation development, ergonomic design integration, and workstation furniture prototype testing; (4) Simulating the workstations: manikin simulation, an overview of ergonomics simulation for the Rapid Upper Limb Assessment (RULA) test, software packages for performing RULA analysis, and finite element analysis (FEA); (5) Optimising workstations: an overview of optimisation, design optimisation, and optimisation analysis; (6) Fabricating workstations: an overview of workstation furniture manufacturing systems and the workstation furniture design process; (7) Research gaps.

2.1 Assessing Work-Related Risks and Hazards

2.1.1 The Ergonomic Risk Factors

There are three main risk factors, which are fundamentally physical in nature, as illustrated and shown in Figure 2.1 (Cheng et al., 2016):

2.1.1.1 The Forceful Exertions

The forceful exertions typically create greater demands on the joints, muscles, and tendons. Increased force also indicates heightened physical needs, such as greater muscular effort. The level of strain on the muscles and joints is influenced by several factors, including the height at which the load must be lifted and the frequency of lifts. There are no specific limitations, such as weight restrictions, in the regulations. High force loads are manageable for the human body across various work tasks, and high force demands cause muscles to exert more effort, which increases associated fatigue and can lead to MSD (Wang & Chen, 2012).

Keir et al., (2021) found a strong correlation between intense exertion and carpal tunnel syndrome (CTS), epicondylitis, and conditions related to the hand and wrist tendons. The relationship between epicondylitis and the dosage response of CTS was identified. Additionally, the multiplicative effects of risk factors on injury risks and hazards are demonstrated through interactions. A dosage response between the risk factors and injuries is further supported by animal models and laboratory research that show clear correlations between task demands and the biomechanical measurements associated with upper extremity injuries.

2.1.1.2 The High Task Repetitions

The high task repetition refers to jobs and processes that require performing the same actions repeatedly. Consequently, they are usually managed through work procedures and hourly or daily production targets. Many jobs and cycles are inherently repetitive, typically governed by these work processes and production targets. Moreover, when combined with other risk factors, such as uncomfortable postures and high force, high task repetition may contribute to the development of MSDs (Ghoual, 2019; Pavlovic, 2013).

2.1.1.3 Awkward Postures

An awkward body posture refers to a position that significantly deviates from the neutral stance while performing work and task activities (Yale & Safety, 2018). Additionally, when lowering, lifting, or handling loads with the back bent and twisted, as opposed to keeping the back straight, extra stress is placed on the back discs, which is influenced by body postures. Similarly, jobs that require extensive time spent working above shoulder height can be very demanding and stressful (Wang & Chen, 2012; Rupasinghe & Panuwatwanich, 2020; Hambali et al., 2019; Safety et al., 2009).

According to Chen et al.,'s (2017), awkward postures in construction operations present significant risks and hazards for both short-term stress and long-term injuries. Reducing and avoiding workers' exposure to awkward and uncomfortable postures is achievable with the aid of motion capture technologies for body posture recognition. Additionally, research by Ezugwu et al., (2020) indicates that, despite variations in awareness levels among the variables, there is a positive correlation between awareness of awkward body postures and repetitive motions as ergonomic factors related to MSDs.

Figure 2.1: The risk factors

2.1.2 Methods for Assessing the Ergonomics of Workstations

There are numerous tools available for assessing the ergonomic of the workstations, including the Rapid Entire Body Assessment (REBA) and the Rapid Upper Limb Assessment (RULA), as well as various forms of ergonomic equipment and questionnaires to monitor the extent of existing symptoms. These evaluation methods are essentially analytical processes that measure job task behaviors over time to assess the physiological demands of job tasks on workers. In essence, these assessment methods involve measuring the requirements placed on both a person and a machine, their interactions, and the effects of various environmental conditions (Rittel, 2010):

2.1.2.1 Ovoko Working Analysis System (OWAS)

The ovoko working analysis system (OWAS) is a method developed in 1977 for the steel manufacturing industry, but due to its simplicity of application, it has been generalised to other fields. Furthermore, one of the earliest software implementations occurred in 1991 using the OWAS method. Professionals have assessed the results of the OWAS method over time. Similarly, the OWAS method allows for the assessment and validation of the physical load resulting from work postures. This strategic method considers postures from a comprehensive perspective; it may be less precise than other strategic methods. Despite being one of the older methods, it remains one of the most popular approaches to assessing postural load in the manufacturing industry, as it can account for numerous postures over time. This is the primary method used to evaluate ergonomic risks and hazards, making it the most widely described today.

The OWAS method is an observational and strategic approach. The procedures of the OWAS method are (ergonomic workplace design in an assembly line, 2022):

1. Determine whether the job is simple or complex (which may be divided into simpler job tasks).
2. Determine the duration of the observation based on the amount and frequency of the adopted postures.
3. Establish the sample rate, which is the period during which the worker's posture will be measured.
4. Observe and record body postures.
5. Codify the observed postures.
6. Assign hazard and risk categories.
7. Determine the percentage of repetitions and the relative frequency of each participant's position.
8. Assess the hazard and risk category for each body part based on relative frequency.
9. Determine appropriate corrective and design measures based on the results obtained.
10. If changes have been made, re-evaluate the work task using the OAS approach to ensure that the enhancements and improvements are effective.

2.1.2.2 Rapid Upper Limb Assessment (RULA)

The Rapid Upper Limb Assessment (RULA) is a method developed in 1993 by McAtamney & Corlett at the University of Nottinham, aimed at evaluating hazards and risk factors for workers. They also noted that the RULA method imposes a high load on body posture, which can be detrimental to the upper limbs of the human body. To assess the RULA method, factors such as posture, duration, frequency of exposure, and forces exerted are considered (Khan et al., 2022). Each body posture is scored, establishing a performance level. This performance level indicates whether the body posture is acceptable or what changes are necessary for the workstation. It is essential to observe several work cycles and select the postures for evaluation. The RULA method should be applied to the right and left sides of the human body separately or to the side with greater postural loads. The procedures of the RULA method are (ergonomic workplace design in an assembly line, 2022):

1. Establish job cycles and observe the worker during several of these work cycles.
2. Select the postures for evaluation.
3. Determine which side—right, left, or both—will be evaluated.
4. Take the angular measurements.
5. Measure directly on the worker using angle protractors, electronic goniometers, or any device that allows for angular data collection; photos can also be utilised to ensure that the angles measured are accurately represented in the images.
6. Determine the scores and ratios for each part of the human body.
7. Calculate the partial and final scores and ratios of the RULA method to assess hazards and risks associated with each body posture and develop an action plan.
8. Identify the measures to implement within the action plan.
9. Design the workstation according to the previous point.
10. Re-evaluate the new body posture using the RULA to check the effectiveness of the measures.

2.1.2.3 Rapid Entire Body Assessment (REBA)

The Rapid Entire Body Assessment (REBA) is a method that evaluates the load posture of the human body based on the RULA method. In this context, it also includes an assessment of the lower extremities. The REBA method takes into account other factors such as the load handled, the grip, and the muscular activity exerted by the worker. The repetition of poor body postures leads to risks and fatigue that can result in health issues. This is typically linked to the high postural loads that can be caused by MSDs. Therefore, it is crucial to assess these loads in a workstation environment. It is important to consider the presence of sudden changes in postures and/or instabilities. The main steps for using the REBA method are (ergonomic workplace design in an assembly line, 2022):

1. Determination of work cycles and observation of the worker during multiple work cycles.
2. Select work cycles where posture, duration, and frequency exceed neutral body position.
3. Determine the side to be measured and tested.
4. Obtain angular measurements of body position.
5. Determine scores and ratios for each part of the human body using the standard tables of the method.
6. Calculate the final score to assess risks and establish if actions are necessary.
7. Identify potential actions that could be taken.
8. Design positions that implement the changes.
9. Re-evaluate body posture using the REBA method to assess the effectiveness of the improvement.

2.1.2.4 Rapid Postural Assessment (RPA)

The Rapid Postural Assessment (RPA) is not a standalone method; rather, it serves as a tool for a brief and swift evaluation of the body postures adopted by the worker. If the

RPA indicates a high level of static load, a more comprehensive study should be conducted using more precise postural evaluation tools such as RULA, OWAS, and REBA. This tool generates a numerical value based on the body postures the worker adopts and the duration for which they are maintained.

2.1.2.5 Vibration Monitor

A vibration monitor controls the oscillatory signals to which the worker is subjected within an organised system of three orthogonal axes. An accelerometer, which is a component of the vibration monitor, measures properties such as the magnitude of acceleration, direction, frequency, and exposure time. Additionally, the accelerometer generates an analysis by producing an electrical signal that is proportional to the acceleration it detects. This measurement is displayed in meters per second squared (m/s^2) to correlate with the units of acceleration received. It serves as a common tool for evaluating both the vibration of the tool itself and the vibrations transmitted to the worker through their interaction with the machinery (Harada & Griffin, 1991).

According to Koc & Liu, (2013), the measurement taken on the production of the instrument will not necessarily reflect the contact that the worker experiences. This is due to the transmissibility and the instrument's ability to transfer vibrations to the operator's and user's hands. The transmissibility is highly variable and genuinely depends on the materials from which the tool is made and their capacity to transfer and absorb individual vibrations. According to Wiley, (2004), workers with high hand vibration exposures are typically subjected to acceleration levels of four to five meters per second squared (4 to 5 m/s^2). Vibration monitoring employs an accelerometer to record information that determines the magnitude of acceleration, direction, frequency, and exposure duration to manage and mitigate hazardous vibrations affecting human body posture.

2.1.2.6 Manual Goniometer

The manual goniometer is a tool used to measure joint angles and control the range of motion stresses for a specific job task. The manual goniometer is effective in managing the precise range of motion utilised. When paired with recorded video footage, it becomes possible to track the entire range of motion throughout the completion of the task. The recorded angles of flexion and extension can be compared to the practical limits estimated for the task.

2.1.2.7 Video Analysis

Recorded video analysis is the process of using a camera or camcorder to capture the interactions between the worker and the equipment they use. For the researcher to assess combined movement effectively, the video analysis should be recorded at a 90-degree angle to the subject. This allows the manual goniometer to be utilised most efficiently, enabling researchers to break down the procedure step by step. The current literature review on evaluation and motion (2023) states that before researchers begin recording, they should have a clear understanding of the purpose of using adhesive tape.

A camera and camcorder are excellent tools for capturing countless details that cannot be fully conveyed through specifications, proving that a picture is worth more than a thousand words. Furthermore, video analysis can document movements and gestures involved in a work task that note-taking or still images might overlook, providing the scholar with a more reliable method of recording actions. It is also advisable for the video analysis to begin wide to showcase the entire process and then zoom in on specific aspects of the procedure from various angles. The video analyses serve as instant replays, giving the economist a second perspective and an additional opportunity to make the right decision.

2.1.2.8 Force Gauge

The force gauge is an instrument designed to assess the muscular effort exerted by a worker while performing a task. This device typically features a mechanism that compresses a weight continuously, which is recorded by the gauge and dial to demonstrate the task that has been performed. These devices are used to evaluate forces involved in tasks such as pulling, pushing, and tensile tests. There are two distinct types of force gauges: hydraulic dynamometers and spring mechanical gauges. Spring scales generally have an accuracy within one percent of the full scale and are available at load levels ranging from just a few grams to thousands of kilograms. Being within 1% of the full scale means that the force gauge accuracy should be within 99% of the actual force being recorded. Hydraulic dynamometers provide results that are more accurate than their spring mechanical counterparts.

2.1.2.9 Questionnaire

A questionnaire is a quick and straightforward method to gather relevant information on the work-related risk factors that contribute to the tasks being performed. By analysing the evidence provided, it is possible to determine which worker groups and workstations should be prioritised for further ergonomic assessment. However, the determination of exposure levels has its limitations with the questionnaire method. The data collected may be substantial enough to rank the units according to their exposure and contact levels (Hildebrandt et al., 2001). Research by Dickinson et al., (1992) stated that a questionnaire typically includes several sections, such as an overview of the survey and its significance. Additionally, it provides information on how to complete the survey and scores the questions designed to meet the survey's objectives. A questionnaire is a quick and simple method to acquire information about the relationship between work practices and the associated risk symptoms arising from these tasks. The core questions of the survey are designed to gather information in these sections (Rittel, 2010):

1. Background variables (gender, age, and length of employment).
2. Tasks (demands of the tasks).
3. Miscalculated risk workload (forces, postures, and movements).
4. Health related to miscalculated risk symptoms.
5. Workers' lifestyle (smoking, sports, and activities).
6. Suggestions for process development.

2.1.2.10 National Institute for Occupation Safety and Health (NIOSH)

The National Institute for Occupation Safety and Health (NIOSH) is a lifting tool that collects information about the tasks performed and records this data to calculate the Recommended Weight Limit (RWL). Furthermore, the RWL is determined by multiplying various task variables, and data will be gathered through interviews and direct observations of workers involved in the tasks. Additionally, the NIOSH equation is utilised to assess manual handling at workstations and to identify hazards and risks associated with tasks such as lowering and lifting (Khan et al., 2022).

2.2 Determining Anthropometric Measurements

2.2.1 An Overview of Anthropometry

Anthropometry is the science of human body measurements and serves as an indicator of well-being and health. It is a division of human disciplines focused on measuring the weight, size, and parts of the human body to achieve usability, comfort, and fit (Dorjee & Sen, 2018). According to Chao & Wang, (2010) and Klamklay et al., (2008), anthropometric data also provides insights into the static dimensions of the human body in standard postures. The measurement of the human body and limbs is essential information for designing workstations, clothing, and hand tools, as well as workstation furniture, machines, devices, and working environments for individuals with disabilities, along with many other products for human use.

In industrialised countries, numerous studies have been conducted on the anthropometric measurements of various workers across different sectors. However, research focusing on the anthropometric dimensions within the garment sector is limited. Furthermore, there is a lack of studies specifically addressing the anthropometric measurements of garment workers. Among these studies, Del, (2007); and Leilanie, (2004) highlighted the importance of height anthropometry measurements of garment workers in their working postures. An earlier study by Sealetsa & Thatcher, (2011) emphasised the significance of anthropometry in designing work tasks (e.g., work task cycles and cooperative work), workstations (e.g., task height, table shape, task angle, and adjustable tables and chairs), and workstation equipment (e.g., needle angle and sewing machine table design).

Several previous studies by Hanson et al., (2009); Pessiot et al., (2010); and Sheta et al., (2018) have stated that anthropometry is the science of measuring human body form, which can help clarify the challenges posed by the human body and its interaction with the working environment. When designing any product, designers and engineers must rely on scientific anthropometric measurements to create seats that accommodate the largest number of people. Otherwise, the result may be a non-ergonomically designed product, contributing to biomechanical strains and increasing the hazards and risks of cumulative trauma and carpal tunnel syndrome for workers. Therefore, using anthropometric data is also essential for the design and implementation of safe tools.

Additionally, a previous study by Taifa & Desai, (2017) notes that anthropometry has three main principles, which are primarily followed in the design of various products depending on the final outcome. The first principle is ″design for the extreme individual″, which may involve designing for the maximum population, usually referred to as the 95th percentile male/female, and/or designing for the minimum population, typically referred to as the 5^{th} percentile male/female. The second principle is ″designing for an adjustable range″, which considers both the 5^{th} percentile male/female and the 95^{th} percentile male/female to accommodate 90% of the population. Many researchers have suggested that the adjustability principle is the main ergonomic guideline to follow when designing workstation furniture. The last and third principle is ″designing for the average″, which is typically used when adjustability is impractical.

2.2.2 A Brief History of Anthropometry

Anthropometry has long been used as a measure of human body variation, and since it assesses external morphology, it is intuitively understood at an elementary level. By standing at any major junction in a city around the world, one can easily marvel at the variety of human physical diversity, such as: tall, short, thin, long-legged, fat, and stumpy. Native wit lends authority to the study of anthropometric measurement variation and its applications (Ulijaszek & Komlos, 2010). Previous research by Komlos, (2018) stated that the concepts of biological variance among human populations are of great antiquity but became quantitatively formalised in the nineteenth century. Additionally, early attempts to address this issue took place in the eighteenth century, prior to innovations that identified variation at microscopic levels, including physiological, biochemical, endocrinological, and genetic factors. Morphology was the primary means of classifying nature.

In the earlier study by Floud, (2004), the strength of anthropometry as a measure of human body variation lies in its relative affordability and simplicity of application, although accuracy remains a concern. It is unsurprising that anthropometric measuring methods have changed little during the nineteenth century. The interpretation and significance of anthropometric data variation have evolved alongside new understandings of how human body variation is maintained and generated. With this shift in meaning has come a change in usage as well, transitioning from racial classification to international public health and the history of anthropometric measurement.

2.2.3 Application of Anthropometric Data

The application of anthropmetric data is described for designing industrial workstations. It is necessary to obtain relevant information on work task performance, body posture, equipment, and the working environment. In cases of new workstation design, it is advantageous to gather more information from similar task situations, such as several tools and methods. These may include direct observation, one-on-one interviews with experienced workers, videotaping, and questionnaires (Gupta, 2014). Before designing any workstation in the industry, it is desirable to conduct a worker survey using appropriate questionnaires to assess the impact of existing and current equipment. The existing equipment must prioritise worker comfort, health, ease of use, and maintenance, while the objectives of such a survey should be documented and/or recorded. For example, the general rating of various tools and equipment, system design, and environmental factors such as noise, temperature, light, and the workstation should be considered (Gupta, 2014).

2.2.4 Anthropometric measurements

People have always analysed and studied the human body, the anthropometric data is measured from childhood to old age, encompassing a wide diversity of ethnic groups, serving as an indicator of health and nutritional status (Lu, 2003). In addition to the dimensions of the human body, such as stature, breadth, and length, anthropometry also describes the mass of the human body. This including weight, center of gravity, and parameters of human body strength and motion that establish mass properties, physical geometry, and the strength capabilities of the human form (Khadem & Islam, 2014).

According to previous studies by various researchers, such as Hsiao et al., (2002); İşeri & Arslan, (2009); and Kalınkara et al., (2011), anthropometric data is one of the essential factors in designing the human body, machines, devices, tools, vehicles, and PPE to achieve optimal design for high performance and productivity. Anthropometric data has been measured as the fundamental core of ergonomics in an effort to address the issue of fitting people to machines, which should be ergonomically adjusted to products and workstations. Several earlier studies, including (Kalınkara et al., (2011); and Wang et al., (1999), stated that anthropometric data pertains to the division of the human body that deals with body measurements, which indicate people's health status. Earlier research by Chuan et al., (2010) noted that any designs incompatible with the anthropometric measurements of a workforce could lead to undesirable incidents.

Previous research by Hsu & Yu, (2010) indicated that the accidental causal factors included the use of hand tools and machinery, unsafe mechanical and physical conditions, and unsafe practices. Hand anthropometry tools are valuable for assessing various aspects of industrial machine hygiene, medicine, and other applications related to designing tools and machines for improved efficiency and enhanced human comfort. According to Chao & Wang, (2010), quickly and accurately obtaining and estimating anthropometric measurements significantly impacts society today. Designing a product without incorporating the anthropocentric measurements of users is problematic, as human body dimensions and measurements vary by age, gender, race, and nationality. Therefore, it is advisable to consider essential anthropometric measurements and dimensions when designing workstations for workers.

According to Mousumi, (2015), one of the most important natural variables that emotionally impact the physical characteristics of the human body is hereditary structure. Moreover, gender is a factor that affects physiology and body ratios, revealing significant differences between males and females that should not be overlooked in a single design. Anthropometric data has significantly contributed to the ergonomic design of workstations in the manufacturing industry. Creating an anthropometric database typically requires considerable resources, including equipment, workforce, machinery, and funding. As previously mentioned by M. Ali, et al, (2014), anthropometric data is utilized in ergonomic workstation design to specify the physical dimensions of workspaces, equipment, workstation furniture, and clothing. Additionally, the phrase ″in shape the task to the man″ emphasises the importance of avoiding physical mismatches between product dimensions and equipment dimensions that align with user dimensions. Generally, anthropometric measurements are expressed as percentiles, with a percentile defined as a statistical measure representing the value below which a given percentage of observations in a group fall. For example, the 95th percentile is the value below which 95 percent of the observations may be found.

2.2.5 Types of Anthropometric Measurements

There are two types of anthropometric measurements: static (structural) anthropometry and dynamic (functional) anthropometry (Man, (2011):

2.2.5.1 Static (Structural) Anthropometry

Static (structural) anthropometry refers to skeletal dimensions that measure the distances between the joint centers of bones, it also includes some soft tissue measurements in contour dimensions, such as the wobbly staff that encompasses all body muscle, skin, fat, and bulk.

2.2.5.2 Dynamic (Functional) Anthropometry

Dynamic (functional) anthropometry refers to the measurements taken when the human body is in motion and engaged in physical activities, such as reach (e.g., the arm plus the extended torso), clearance (e.g., two people passing through a doorway), volumetric data (e.g., the effective area for a specific work task), and kinetochore.

2.2.6 Anthropometric body dimensions

The anthropometric body dimension refers to the measurement of the human body, which provides the foundation for developing information for models used in pattern making. There are subtle differences among individuals, and human body dimensions fit within a standard range that has varied significantly across different times and regions. The anthropometric human body dimension also offers a recommended list of data requirements for gathering human body measurements (Khadem & Islam, 2014). A previous study by the Mousumi, (2015) noted that anthropometry consistently examines human body dimensions in either the coronal or sagittal plane. It also maintains two standard postures: standing body posture and sitting body posture, which are described below (Pereira et al., 2014):

2.2.6.1 Standing Body Posture

The standing body posture involves the person looking straight ahead and standing erect with a relaxed demeanor. For standing measurements, the posture should generally include looking straight ahead, heels together, an upper body that is relaxed, and normal breathing (Pereira et al., 2014).

2.2.6.2 Sitting Body Posture

The sitting body posture involves the person looking straight ahead and sitting upright, with the sitting surface adjusted so that the thighs are parallel to the ground and the knees form a 90º angle, with the feet flat on the floor. Additionally, the upper arm should be comfortable and vertical to the horizontal surface, while the forearm is positioned at the correct angle to the upper arm, remaining parallel to the ground. Furthermore, measurements in a sitting posture are taken using a horizontal reference point, either the floor or the seat, and a vertical reference point is an imaginary line that traces the back of the uncompressed shoulder blades and buttocks of the individual. Consequently, in the standard body posture, the person should be measured with the major joints, such as the knees, ankles, hips, and elbows, positioned at 90º angles

According to Chuan et al., (2010), variations in lifestyles, nutrition, and national groups among populations lead to differences in human body dimensions, necessitating regular updates to anthropometric data collections. The variation in body dimensions among individuals, based on race and sex, can complicate product design. Designing equipment and/or tools to accommodate all human body types and sizes is challenging;

therefore, designers and engineers must prioritize the significance of these dimensions. For measurements of sitting postures, the torso should be erect, shoulders relaxed, the subject should look straight ahead, and the feet should be supported so that the femurs are horizontal and parallel to each other. Achieving horizontal femurs can be facilitated by an adjustable foot platform or a series of platforms of varying thickness that can be combined to attain the desired posture.

2.2.7 Significance of Integrating Anthropometric Data in Workstation Design

All products of the workstations are ideally designed using user-centered design processes, where data is taken into account. Anthropometry data is the branch of human body sciences that focuses on the measurements of weight, size, and proportions of human body posture to achieve fit, comfort, and usability. In an ideal design process, the data is compared with relevant product workstation dimensions, such as chair height relative to personal height (Hanson et al., 2009). According to Pentikis et al., (2002), all product designs, including consumer products, clothing, and product systems, as well as the fit between different workstation products and users, are not consistently optimal.

Westgaard & Aarås, (1984) argue that improper product design of workstation adjustments to anthropometric features results in pain, discomfort, and disorders in the neck, arm, shoulder, hand, wrist, and back. Furthermore, the resulting MSDs have been observed in various contexts, including the driver environment and the office of the electronic assembly line (Sundelin & Hagberg, 1989). To minimize the poor anthropometric alignment between product design, workstation design, and users, designers and engineers must utilize accurate and updated anthropometric data for each object group (Nickpour & Dong, 2011). According to Williams et al., (2004), integrating anthropometric data (measurements of human body sizes and dimensions) into new product design can provide a more precise foundation for evidence-based design decision-making.

2.2.8 Anthropometric Considerations for the Workstation

Anthropometry is the collection and measurement of the physical dimensions of the human body and posture, ultimately used to enhance human fit in the workstation and identify issues between facilities, equipment, and the workers using them. Research by Mayfield, (2007) indicates that clearance, reach, posture, and strength are the four primary constraints utilised in ergonomic design. The 95% confidence level signifies that the design accommodates the smallest and largest users within the 95^{th} percentile of a specific population. This implies that the smallest 2.5% and the largest 2.5% of the population are excluded from design considerations. These percentages are omitted because the 95^{th} percentile between them ensures the greatest accommodation, operability, compatibility, and maintainability for average-sized users (Iberes & Giovana 2000).

According to Iberes & Giovana (2000), the approach allows the workstation to be designed to accommodate the maximum number of workers possible within the selected percentile. Some key ideas that can help determine the distances needed for certain controls indicate that clearance should always accommodate the maximum number of users, while reach should always accommodate the minimum. A workstation is designed to fit each individual worker, but with shrinking budgets and workforces, it becomes increasingly difficult for a company to afford changes that fit the worker. Anthropometrics is critical in ergonomics because it takes the dimensions of workers and applies them to the design of workstations, tools, jobs, and equipment. Several features characterize a well-designed job, such as: physical dimensions that ensure reaches, clearances, and work heights accommodate the capabilities and features of at least 90 percent of workers; peak loads that remain within the strength and/or endurance capacities of at least 90 percent of workers; environmental factors that do not impose improper risks and/or performance limits on the healthiest workers; cognitive, perceptual, and visual demands that align with the dimensions of most workers, including older ones; job repetition rates and striding that are not excessive; and workers having control over their job patterns.

When designing a workstation, it is best practice to use dimensions that accommodate at least 90 percent of workers. This approach allows for greater interchangeability, enabling multiple workers to perform the same tasks in the workstation environment. By maintaining average mental and physical demands, designers and engineers enable a diverse range of workers to complete the tasks effectively. The principle behind ergonomic workstation design is that a healthy, normal adult should be able to perform the tasks within a company, allowing managers to recruit from the primary pool of available workers (Rittel, 2010). A study by Young, (2009) indicated that in job design, reducing static exertion without the motion element of any task may prevent local muscle weakness from limiting productivity. Most industrial work involves both static and dynamic tasks. While static work is more likely to limit productivity, it is generally advisable to minimize the static component of tasks whenever possible.

Furthermore, there are several guidelines for workstation and task design aimed at reducing static effort, which include: avoiding forward reaches of more than 15 inches while sitting and more than 20 inches in front of the body when standing; designing foot pedals to minimize or eliminate the need for sustained pressure and providing rest breaks for highly repetitive job tasks. These design guidelines are recommended to ensure that a task is not exhausting or overworking the worker. By reducing the manual effort required in a task, the company will create a more favorable environment for the worker, promoting higher productivity (Rittel, 2010).

2.3 Designing an Ergonomic Workstation

2.3.1 An Overview of Ergonomics Science

The fundamental philosophy of ergonomics is to design workstations that promote safety, comfort, convenience, and physical health, while also motivating individuals in their studies (Taifa & Desai, (2017). According to Koirala, (2022), ergonomics is the careful design of equipment that enables people to work more efficiently and effectively in their environments. To achieve this, it applies physiological and psychological principles to the engineering and design of workstation systems and processes. The ergonomics approach involves studying task design in relation to the psychological and physiological capabilities of individuals. The goal of ergonomics is to evaluate and design jobs, facilities, environments, training methods, and tools to align with the abilities of users and workers, thereby reducing the potential for errors, fatigue, and unsafe actions. Furthermore, from an ergonomics perspective, when most potential workers can perform well without excessive stress, it is essential to ensure thoughtful design (By & Meister, 1995).

Research by Cañas et al., (2011) and Wibowo & Mawadati, (2021) indicates that ergonomics science can be applied across a wide range of disciplines within the manufacturing industry. For instance: architecture, anatomy, product design, physiotherapy, physics, psychology, occupational therapy, and industrial design engineering. Additionally, numerous studies have reported improvements in efficiency and product quality in the manufacturing sector, alongside reductions in injury rates and increases in job comfort and satisfaction for workers. Ergonomics science involves the application of scientific principles, approaches, and data drawn from various disciplines to develop manufacturing systems where people and societies play a significant role. Key disciplines include cognitive science, psychology, physiology, biomechanics, applied physical anthropometry, and industrial engineering systems (Shamsuddin et al., 2015). According to Dul et al., (2012), the international ergonomics association (IEA) defines the field of ergonomics as follows: Ergonomics, or human factors, is the scientific discipline concerned with understanding the interactions between the human body and other essential components of the system. Ergonomics is also a profession that applies principles, theories, data, and approaches to design in order to optimise human well-being and overall industrial system performance. Economists contribute to the design and evaluation of tasks, jobs, products, environments, and industrial systems to ensure they align with the needs, abilities, and limitations of people.

Research by Simonsen & Berlin, (2017) states that the primary purpose of ergonomics is to study the conditions of people at work and play, thereby improving the overall situation for individuals. Ergonomics is always user-centered and focused on the user's well-being rather than solely on productivity. Although directors and designers sometimes require justification for enhanced productivity and efficiency to implement ergonomic science in industrial systems, the aim of ergonomics can be described as aligning the system and product with the user. Furthermore, among the fundamental disciplines contributing to ergonomics are psychology, cognitive science, physiology, biomechanics, applied physical anthropometry, and industrial systems (Interaction Design Foundation, 2017). According to Krishna, (2019), ergonomics originated from the importance of design and the operational challenges presented by new work systems that have evolved with technological advancements. Two approaches, namely: fit the man to the job (FMJ) and fit the job to the man (FJM), have been recommended as viable alternatives to enhance and sustain the productivity and efficiency of human-machine work systems, with work satisfaction, health, and the capabilities of the human body as core issues or objectives. It has also become evident that FJM is almost always the superior method for designing work systems.

The underlying expectations of the FJM method are that a suitable set of worker characteristics can be identified for which a task can be designed, and this can be applied to any task. The content of ergonomics primarily focuses on relating these characteristics at the physiological, anatomical, and psychological levels and explaining their design implications; only under specific circumstances can the FMJ method be the sole option. For example, workers who need acclimatisation must operate in hot conditions that should remain unchanged, and there may be various FJM options, such as creating a better work-rest schedule and providing protective clothing (Krishna, 2019). According to Mehta, (2016) and Zhang & Zhang, (2005a), the field of ergonomics was established by economists to address practical issues in the design and manufacturing of workstation products and systems, and it is typically divided into the areas of physical ergonomics, cognitive ergonomics, and organizational ergonomics.

Some explanations of the sub-fields of ergonomics are provided by (Zhang & Zhang, 2005b), which include cognitive ergonomics, related to mental processes such as awareness, thinking, cognition, and response, as these affect the relationships between the human body and various factors of the engineering system. Issues related to cognitive ergonomics encompass psychological workload, human dependability, decision-making, skilled performance, capability, and training, all stemming from the interaction between individuals and the system. Additionally, physical ergonomics focuses on human structure concerning anthropometric, physiological, and biological features in relation to bodily activity. The principles of physical ergonomics are commonly applied in the design of both consumer and manufacturing workstation products.

Moreover, the most prevalent types of work-related tasks associated with injuries are MSDs linked to repetitive tasks, integrated into work processes, and poor working environments (Britnell et al., 2006). Therefore, to enhance worker efficiency and reduce the risk of MSDs, the workers must assess their body postures and implement appropriate measures. A significant issue in industrialised countries today is the WRMSDs associated with repetitive work environments. These issues can be defined as weak human bodily structures, including muscles, joints, tendons, ligaments, nerves, bones, and the local circulatory system, which arise primarily from similar procedures or work conditions (Britnell et al., 2006). According to Scott & Erin, (2006) and Bailey et al., (2023), organisational ergonomics focus on improving social systems. This encompasses organisational structure, processes, and policies related to communication, resource management, participatory and collaborative teamwork, community work conditions, new work programs, virtual organisations, and quality management. Additionally, the areas of specialisation within the field of ergonomics or human factors can be broadly categorised as illustrated in Figure 2.2.

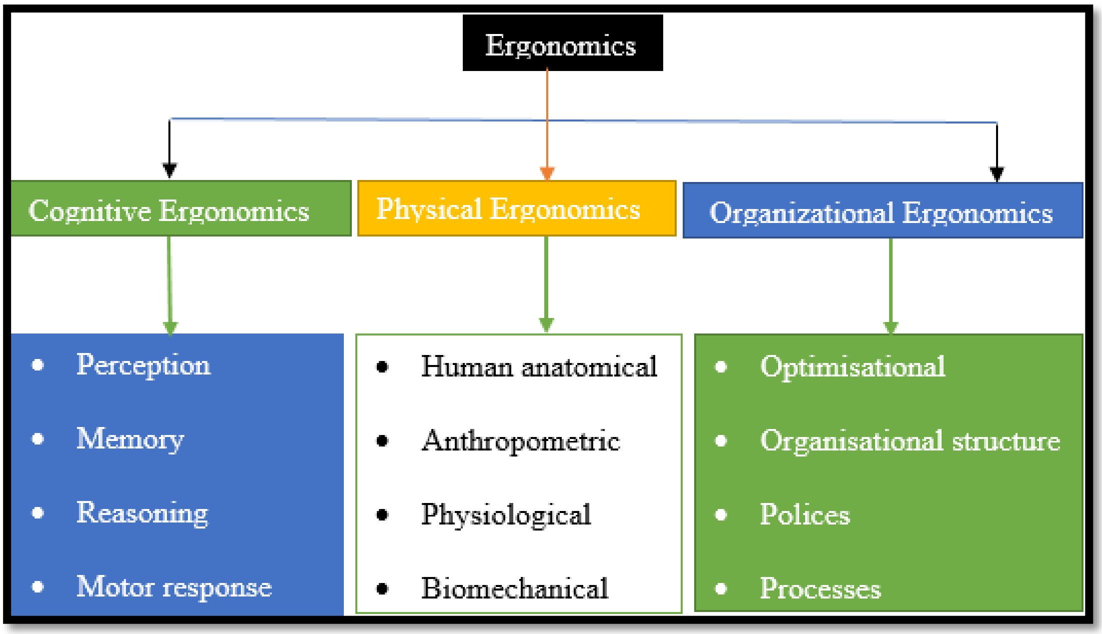


Figure 2.2: Classification of the sub-fields of ergonomics

2.3.2 A Brief History of Ergonomics

Although ergonomics has undergone many changes throughout its long history, some developments, such as cognitive ergonomics in the 1960s, organisational ergonomics in the 1970s, positive ergonomics in the 1980s, emotional ergonomics in the 1990s, and spiritual ergonomics in the new millennium, have sparked debate. Positive ergonomics typically focuses on enhancing the human-machine system to create a more enjoyable work environment, allowing individuals to feel comfortable and satisfied. Emotional ergonomics examines how people's emotions interact with machines. Spiritual ergonomics is based on the idea that workers' passions significantly influence their success and well-being (Koirala, 2022). As noted by Krishna, (2019), the emergence of ergonomics as a distinct field of study is a relatively recent phenomenon. The concept of ergonomics has roots in ancient times; during the Stone Age, individuals designed hand tools to suit both the user and the task. Additionally, during the Industrial Revolution, efforts were made to apply human-centered design principles to tools, aiming to assign engaging jobs to people while relegating repetitive tasks to machines. When ergonomics was formally recognized after World War II in the United Kingdom, its focus shifted to equipment and workstation design. See Appendix II for some ISO standards related to ergonomic design, which encompass relevant subjects such as physiology, anatomy, industrial medicine, architecture, design, and illumination engineering.

In Britain, the ergonomics research society was established in 1950, and in various parts of Europe, particularly Germany, France, the Netherlands, and the Scandinavian countries, ergonomics is a well-established discipline and research field. Even labor unions are actively focusing on its advancement, recognising its importance for health, safety, convenience, and comfort. In the United States, human factors or ergonomics emerged as a discipline in the early fifties. As previously mentioned by Krishna, (2019), ergonomics or human factors share much in common, although their development has followed different paths. Ergonomics or human factors have achieved remarkable success in designing large systems within the workstation industry at the National Aeronautics and Space Administration (NASA) and its space system programs.

The Eastman-Kodak and International Business Machines (IBM) are two companies, among others, where ergonomics have been significantly applied, with many of these programs undertaken by company nurses and industrial engineers. Other agencies in the field of ergonomics and human factors have sponsored studies on civilian applications, including the design of highways and road signs, human capabilities and limitations in space, car design, the effects of drugs and alcohol on driving, industrial safety, ergonomics in underground mining, workstation injuries, job stress, safe design of consumer products, design requirements for nuclear power plants, and aviation safety. Recently, the Human Factors Society (HFS) in the United States has changed its name to the Human Factors and Ergonomics Society (Krishna, 2019). Both human ergonomics and factors engineering utilise the FJM method, asserting that jobs should be tailored to fit people rather than the other way around. Basic human features in the context of job design and analysis have been examined by economists; however, as this is a developing and interdisciplinary subject, the limitations of ergonomics remain unclear.

Additionally, in India, the application of ergonomics has been quite controversial thus far, given the vast size of its industrial and agricultural sectors. Only a few individual efforts have been made. The design of productive job systems, operated by motivated, healthy, and efficient individuals, becomes a core issue to remain competitive with the cost-effective approaches and procedures currently in use. It is essential for organisations involved in any product to apply ergonomic principles as a crucial concept for better workstation design, services, and the working environment in the future.

The term ergonomic is derived from the Greek words ERGON, meaning work, and NOMOS, meaning law or usage. According to Esmaeel, (2022) and Gade et al., (2015), the word ″ergonomic″ was first used in 1857 by a Polish researcher named Wojciech Jastrzębowski when he published the book ″The Work Environment or Business Science.″ Similarly, ergonomics emerged as a response to the design and operational challenges posed by technological advancements in the last century. Its development is linked to the same historical processes that led to the establishment of other fields such as occupational medicine and industrial engineering. Ergonomics involves applying scientific knowledge about the human body to the design of objects and systems utilised by people (Sepehri et al., 2013). Ergonomics, or human factors, is a method of working smarter, not harder, by designing tools, equipment, workstations, and tasks to align the job with the worker, rather than forcing the worker to adapt to the job (Al-Hinai et al., 2018). Ergonomics, or human factors, is a profession that employs principles, theories, and data to understand the interaction between the human body and other elements within the system (Kurban et al., 2015).

2.3.3 Benefits of an Ergonomics Process

The benefits of an ergonomics process are explored in the subsequent sections (Khan et al., 2022):

2.3.3.1 Ergonomics Reduces Costs

By systematically reducing ergonomic hazards and risk factors, economists can prevent the costly burden of MSDs, with approximately 1 United States dollar (USD) out of every 3 USD in workers' compensation costs attributed to these disorders. This presents an opportunity for significant cost savings.

2.3.3.2 Ergonomics Improves Productivity

The best ergonomic solutions often enhance workstation productivity by designing tasks that promote good posture, reduce motions, minimise exertion, and optimise heights and reach, thereby making the workstation increasingly efficient.

2.3.3.3 Ergonomics Improves Quality

Poor ergonomics results in frustrated and fatigued workers who are unable to perform at their best. When a task is too physically demanding, workers may struggle to complete it as effectively as they were trained. For example, a worker might not tighten a screw sufficiently due to the high force required, which could lead to issues with product quality.

2.3.3.4 Ergonomics Improves Worker Engagement

A workers' announcement when the factory is making its best efforts to ensure their safety and health. For instance, if a worker does not experience discomfort or fatigue during their workday, it may decrease absenteeism, reduce turnover, improve morale, and increase worker involvement.

2.3.3.5 Ergonomics Creates a Better Safety Culture

Ergonomics demonstrates the company's commitment to health and safety as a fundamental value. The cumulative impact of the previous four benefits of ergonomics results in a more robust health and safety culture within the company. Health workers are the most valuable asset, nurturing and establishing the safety and health culture in an organisation, which ultimately leads to improved performance.

2.3.4 Importance of Ergonomics

Industries increasingly require higher production rates and technological advancements to remain competitive and sustain operations. Consequently, jobs today may involve: frequent lifting, carrying, and pushing or pulling loads without assistance from other workers or devices; heightened specialisation that necessitates the worker to perform a single function or movement for extended periods, day after day, and working more than eight (8) hours daily; and maintaining a quicker pace in tasks, such as faster assembly line speeds and having restricted grips when using tools (Berlin, 2011).

2.3.5 Problems at the Workstation and the Ergonomics

There are several types of problems associated with the task to be performed, such as: humans being responsible for the work; the environment in which human beings operate; and the interfaces between work, humans, and the environment. All of these factors influence and determine the level of human performance and production output at the workstation, regardless of the type and level of technology employed. Moreover, the issues related to these aspects cannot be entirely eliminated. As the technology in use is continuously assessed, no two individuals can perform the same job task in precisely the same manner due to variations in inherent abilities and responses to the work environment and systems among human beings.

The primary focus of ergonomics is the design of the workstation as a cohesive system to achieve optimal performance from humans consistently and continuously. Additionally, interdisciplinary knowledge in relevant fields such as physiology, biomechanics, psychology, engineering, systems design, and cybernetics is essential. These fields are necessary to understand functional requirements, formulate system goals, analyse the system, implement the system, and design new systems. To address any issues of this nature in workstation environments, ergonomics is likely to provide a range of solutions (not just one, but a variety of alternative solutions) that can lead to increased productivity of resources and efficiency of production equipment, safe working practices, improved health and well-being of individuals by minimising risks and hazards, and the design of a maintenance plan for a comfortable work environment. In the long term, operations at the workstation should aim for minimal costs and maximum product quality while ensuring acceptable and standard quality of work life for individuals (Esmaeel et al., 2024).

Moreover, as economists hail from a variety of professional fields, it becomes easier for them, as a collective, to tackle workstation problems in an integrated and holistic manner. For several reasons, the potential of ergonomics has not yet been fully realised, except in some developed Western nations. In developing countries, ergonomic principles have rarely been applied in workstation design. Additionally, a survey indicated that individuals outside the field of ergonomics are largely unaware of its significance. As technology grows more complex, the design of the interface between advancing technical programs and their human users becomes increasingly critical. In the near future, the necessity for successful implementation of ergonomics at workstations is anticipated to be recognised by designers, engineers, and users alike (Ahmed, 2018).

2.3.6 Ergonomics in the Constrained Design Reality

Product design is typically conducted as a development task where stringent constraints on product performance, costs, and timelines are prevalent. Throughout the development process, the design team must consider a comprehensive range of requirements, including technical performance, environmental concerns, market limitations, manufacturing, competition, materials, weight, costs, aesthetics, safety, quality and reliability, installation, packaging, and ergonomics. All these factors must be carefully balanced and ultimately synthesised into an innovative, competitive product that is available on the market at the right time and price.

2.3.7 Designers as Users of Ergonomics Information

To make any real contributions to the design, ergonomics consultants need ways to influence the thinking and behavior of people with significantly different perspectives from their own. The challenge for ergonomics consultants is to establish methods for stimulating, informing, and influencing a design team to effectively address important ergonomics issues throughout the product design process. It should be the ergonomics specialist's responsibility to interpret research findings and begin bridging the research gap by learning to communicate in the language of design. Research by Fulton & Marsh, (2000) notes that ergonomics consultants must create a relationship between synthesis and analysis. They need to facilitate the translation of ergonomics information into a format that stimulates well-conceived and user-centered design ideas. In product design, designers often prefer to obtain precise data rather than general guidelines. Several economists seem to believe their task is complete once they have provided general guidelines and handed them over to designers for implementation and interpretation.

A study by Burns & Vicente, (2000) considers that the influence of ergonomics on design must extend beyond laboratory results and guidelines. Although end users are the recipients of ergonomics, they are not typically the ones utilising the ergonomic outcomes. The actual users are designers and those who create the products and systems, whose decision-making must be guided by ergonomic considerations. According to Bezerra et al., (2017), design is the central achievement of the engineering profession. In today’s context, human-machine interface design, or simple interface design, has become a critical issue; thus, it is essential for design engineers and technologists to be informed about ergonomic principles and human factors. Ergonomic design and analysis have emerged as key areas of study, with extensive research over the past decades aimed at creating workstations that are ergonomically designed, operationally safe, and productive as well.

2.3.8 Difficulties of the Contribution from an Ergonomics Perspective

Usually, economists work in product development, and reports indicate that one of the major sources of dissatisfaction is the potential to make a difference, such as contributing relevant and usable design insights. However, economists argue that ergonomic factors are often overlooked in the design process, relegating ergonomics to a post-design evaluation. This leaves economists with limited opportunities to implement crucial design changes and highlights the significance of the product (Abid et al., 2017). According to Simonsen & Berlin, (2017), most ergonomics professionals have cultivated a strong practice in both written and oral presentations of materials. Many designers and engineers are impatient with lengthy written arguments and tend to prefer visual materials, seeking to grasp the main point quickly and move on. A study by Ullman, (2018) states that design problems are characterised by being ill-defined, having multiple potential solutions, and lacking a clear best solution.

2.3.9 Significance of Integration of Ergonomics in Design

The workers need to have as much ergonomic motivation as possible during the conceptual design phases of the task to ensure that their struggles are directed appropriately. However, today's workers operate at a distance from the broadly diverse societies of the users (Fulton & Marsh, 2000). In many cases, designers are expected to rely on other professional functions, such as ergonomics and market research, to interpret people's wants and desires. The researcher adds that, with support from the authorities, designers and engineers should be provided with ample opportunities to step outside their own culture and experiences to understand what it is like to be someone else. Clearly, mutual understanding, interest, and respect among engineers and economists for each other's capabilities are central to facilitating the efficient incorporation of ergonomics in workstation design. Research by Haslegrave & Holmes, (1994) indicates that it is crucial for economists to grasp the key aspects of design. Both are connected to the process, the product, and business limitations, and it is also essential for engineers to receive formal education in ergonomics, so that both professions can understand each other's approaches to problem-solving.

2.3.10 Engineering and Design

The American Heritage Dictionary of the English Language (AHDEL) defines engineering as the application of scientific and mathematical principles to practical ends, such as the design and manufacture of machines, the operation of efficient processes, and the creation of economical structures and systems. Conversely, the verb "engineer" can mean to manage, plan, and implement. Research by Engelmann et al., (2021) states that engineers' primary task is to apply scientific information to solve technical problems and then optimise that solution within given material, economic, and technological constraints.

2.3.11 Engineering Design and General Design Considerations

Engineering design is a part of human problem-solving activity that begins with recognising a gap in user knowledge, leading to a plan for a new object and culminating in the production of that object (Starovoytova, 2019; Starovoytova et al., 2016). Product design involves conceiving and shaping the goods and services that meet user needs. The following aspects are considered during the design process: simplicity, ease of use, ergonomics, safety, ease of manufacture, aesthetics, availability of materials and labor, durability, reliability, weight and size, operational and maintenance costs, environmental soundness, efficiency, life cycle cost, utility, and function (Madara et al., 2016). Thus, Table 2.1 illustrates the elements of product design using the Ducati Monster motorcycle as an example of a highly popular and successful artifact established in 1993.

Table 2.1: The elements of product design

What are the user needs?	The motorcycle sounds powerful	Reference
What are the target values of the product attributes?	0-100 km/hr. acceleration time < 4.0 seconds, etc.	Starovoytova, (2019).
What is the core product concept?	A naked bike as a raw counterpoint to the faired sport-bikes in the market.	
What will be the overall physical form and appearance of the product?	Typically, the form is initially represented with a sketch and eventually in represented by a 3D (Three-dimensional) computer model.	
What is the product architecture?	Welded tubular frame; Ducati L-Twin engine/transmission hung from frame at four points; chain derive; rear swing arm suspended from transmission casing, etc.	
What variants of the product will be offered?	M900 initial, to be followed by M400, M600 and M750 (differing primarily in engine displacement).	
Which components will be shared across which variants of the product?	Most components except engine shared across all models.	
What are the values of the key product parameters?	90cc engine displacement; 1440mm wheelbase; 14-liter fuel capacity.	
What is the detailed design of the components?	Usually, the detailed design of components is represented with 3D computer models plus annotations for finishes, materials, and other attributes.	

2.3.12 Application of Ergonomics

The primary aim of ergonomics is to optimise the work system's performance by improving the interactions between machines and users. Enhanced performance can be defined more precisely, such as achieving greater output with fewer inputs (increased productivity) and enhanced reliability and efficiency (reduced likelihood of inappropriate connections among the work system components). The precise definition of a better working system varies based on the contexts and principles of ergonomics (Woo et al., 2016).

2.3.13 Ergonomic Impact on Workers' Work Performance

The impact of ergonomic factors on workers' performance in production areas can be leveraged by all industrial initiatives. Ergonomics is a strategy that helps companies attract and retain their best workers at the workstation (Ravindran, 2019). The goal of ergonomics is to enhance the workstation to accomplish more tasks in the least amount of time, energy, and money. Research by Kahare, (2014) suggests that when workplace ergonomics are improved, workers perform better and are less likely to miss tasks or leave their jobs. Ergonomics considers workers' physical, social, mental, organisational, and environmental factors when designing workstation products, jobs, and working environments to ensure they align with their abilities, needs, and limitations. Ergonomics aims to enhance both human well-being and overall work performance using data, theory, principles, and methods. According to Ahmadi et al., (2015) and Mihartescu et al., (2021), ergonomics is a scientific discipline that focuses on how people interact with other components of the system.

A study by Merino et al., (2017) posits that workstation ergonomics is a comprehensive science that examines various factors affecting a worker's comfort and health, including lighting, heavy lifting, noise, temperature, workstation design, tool design, vibration, repetitive motion, machine design, chair design, shoe design, and table design, among others. Research by Hoff & Öberg, (2015) suggests that enhancing work conditions, reducing physical exhaustion, and minimising strain from all activities can improve individuals’ well-being and quality of life at the workstation. According to Al Horr et al., (2016), a poorly designed workstation can significantly impact workers' task performance and overall satisfaction in the work environment. Soewardi et al., (2016) noted that most garment factories strive to make their workstations increasingly comfortable, and the number of garment companies implementing ergonomics in their operations has been on the rise.

Using good ergonomic principles, workers’ well-being and safety can be enhanced, leading to increased productivity. According to Dimberg et al., (2015), the rapid changes in technology have altered the roles of ergonomics; to adapt to these changes, management must involve direct worker participation and awareness in workstation design. A study by Burgess, (2018) suggests that participatory ergonomics systems are the most effective way to rethink and design manual jobs, thereby reducing the incidence of occupational MSDs. Koirala, (2022) argues that for a workstation to comply with ergonomic principles and standards, it must utilise the latest technology to ensure worker comfort. Pickson et al., (2017) believe that regular training at the workstation can help workers understand how to significantly improve ergonomic practices. Furthermore, several reviews indicate that most research on ergonomics is conducted in garment manufacturing and developed countries.

2.3.14 Ergonomics at Industrial Workstation

The ergonomics at the industrial workstation avoid the interactive methodology, where damage-causing tasks are modified to a practical approach that emphasises the assessment of each job. This pertains to safety and feasibility, as the workstation and processes are designed (Attwood et al., 2003). Ergonomics can be an integral part of design, manufacturing, and use. Users can gain a better understanding of ergonomics and see how it impacts the study of human body measurements, repetitive motion, movement, and workstation design as it relates to their needs. According to Attwood et al., (2003), the principles of integrating ergonomics into workstation production aim to enhance procedures through ergonomic involvement in the planning stage of workstation design.

2.3.15 Industrial Workstation Design

Good workstation design relies on the physiological, physical, and psychological needs of the worker. There are two key concepts in workstation design: the workstation itself and the physical area where an individual performs tasks. The main types of workstation designs include sitting workstations, standing workstations, and hybrid workstations that accommodate both sitting and standing. Each type has features that make it more suitable for certain tasks while being less effective for others. Therefore, workstation design should be evaluated alongside process and task data during analysis. The steps to designing a new workstation are: 1) Adaptation; 2) Problem identification; 3) Basic information; 4) Data gathering and analysis; 5) Assessment; 6) Recommendations; 7) Design; and 8) Development (Eswaramoorthi et al., 2010).

2.3.16 Development of Ergonomics in the Workstation

In the design stages of new processes, frameworks, tools, and products, it is common for advanced organisations to consistently prioritise ergonomics. This level is achieved by approximately 5% of all organisations, which can accomplish this through a common and ongoing phase access review process, along with standard design guidelines for ergonomic principles such as accessibility, work height, force, weight limits, and the engineers and designers responsible for product quality. According to Arezes et al., (2015), in recent years, the percentage of people using online software and solutions for office ergonomics has increased from 27% to over 50%. Table 2.2 illustrates the development of ergonomics in the workstation (Kuorinka, 2000a).

Table 2.2: Development of Ergonomics in the Workstation

Period	Event	References
400 Before Christ (BC)	Archaeologists discovered sketches and paintings of Ancient Greek civilizations depicting chairs with back contouring.	Kuorinka, (2000b).
1700s.	Bernardino Ramazzini (1633–1714), an Italian physician, produced an article titled ″De Morbis Artificum″.	
1890s.	Frederick Winslow Taylor started out on a mission to make the workstation more efficient.	
1900s.	Lillian and Frank Gilbreth started looking into ‘Time and Motion Studies.	
1914-1918s.	During World War I, ergonomic innovations for screens, controls, and seats were integrated into airplanes.	
1939-1945s.	Ergonomic ideas found their way into armament and machinery throughout World War II.	
1949s.	The term ″ergonomics″ was coined by physiologists and psychologists at the Admiralty in the United Kingdom.	
1950s.	Military Ergonomics.	Helander, (1997).
1960s.	Industrial ergonomics.	
1970s.	Consumer products ergonomics.	
1980s.	Human-computer interaction and software ergonomics. As computers were more widely used, ergonomic research changed once again to try to understand the human issues involved.	
1990s.	Cognitive ergonomics and organizational ergonomics.	
2000s.	Ergonomics has progressed in leaps and bounds as technology has improved.	
2001s.	OSHA Ergonomic Standard. Renewed efforts underway to re-invent a version.	

2.3.17 Ergonomic Design and Integration

2.3.17.1 A Case Study of Rivatex East Africa Limited (REAL)

The Rivatex East Africa Limited (REAL) is recognised as the home of quality textile products both locally and regionally. The REAL factory has been facing challenges related to machinery and obsolete technology, which have hindered the exploitation of potential opportunities in the local and regional markets. Despite these challenges, the REAL factory has taken several steps toward a complete revival on its path to sustainable growth and profitability. REAL is a vertically integrated textile factory that transforms cotton lint through various processes into finished fabrics (Ednah et al., 2016). It was officially opened on the 4th of August in 2007 as the Moi University facility for training, teaching, consultancy, project work, research, product evaluation, development, and extension. REAL is fully owned by Moi University and was incorporated on the 16th of August, 2007, with the objective of utilising the facility for training, research, learning, extension, and commercial purposes. Additionally, the factory has established an ultramodern apparel and garment-making unit that is well-equipped with state-of-the-art equipment to produce all kinds of outfits from cotton and cotton blend fibers (Ednah et al., 2016).

Through the support of the Kenyan Government, the REAL factory has been able to invest in new and ultra-modern equipment in the textile industry, which is unique and the only one of its kind in Eastern and Central Africa. The REAL factory is a vertically integrated textile plant that includes spinning, weaving, wet processing, and garment operations (East & Limited, 2020). In this study, the garment operations department is selected as one of the pioneering garment industries in Kenya for producing high-quality and excellently finished fabrics. This REAL factory is located at Kipkaren Rd South, 4744-30100, Eldoret, Kenya. See the REAL factory profile in Table 2.3.

Table 2.3: REAL factory profile

Factory name	Rivtax East Africa Limited, factory
Address	Kipkaren Rd South, 4744-30100, Eldoret, Kenya.
Product	Finished fabrics
Buyers	African and Chinese firm.
Number of workers	1000
Certification	ISO
Worker productivity	55% - 60%
Reference	https://rivatex.co.ke

2.3.17.2 Ergonomic Design Principles

The ergonomic design principles, including the use of anthropometric data, workstation design, and the science of seating, are prioritised in creating an ergonomic workstation. Previous studies by researchers such as Chung & Wong, (2007); De et al., (2015); Eladly et al., (2020); Gorce et al., (2022); Khadem & Islam, (2014); Oyewole et al., (2010); Saguyod et al., (2021); Sheta et al., (2018) have indicated that ergonomic workstations promote good body posture, influenced by personal factors, task requirements, and workstation design. Additionally, body posture requirements are illustrated in the postural triangle, as shown in Figure 2.3, while work task requirements encompass cycle time, visual demands, force, manual tasks, rest periods, paced, and in-paced tasks. Personal factors include workers' anthropometric dimensions, age, sex, body mass index (BMI), existing MSDs, and injuries, while workstation design involves seat design, seat dimensions, and work surface dimensions. Furthermore, while work task requirements and personal factors may rarely change, workspace design can be modified when creating an ergonomic workstation. Ultimately, good body posture reduces postural strain and stress, enhancing worker comfort. Utilising anthropometric data in workstation design, along with principles of motion economy and seating science, can aid in developing an ergonomic workstation. The ergonomic design principles that should be integrated into workstation design are discussed in the following sections (Ahmed, 2018):

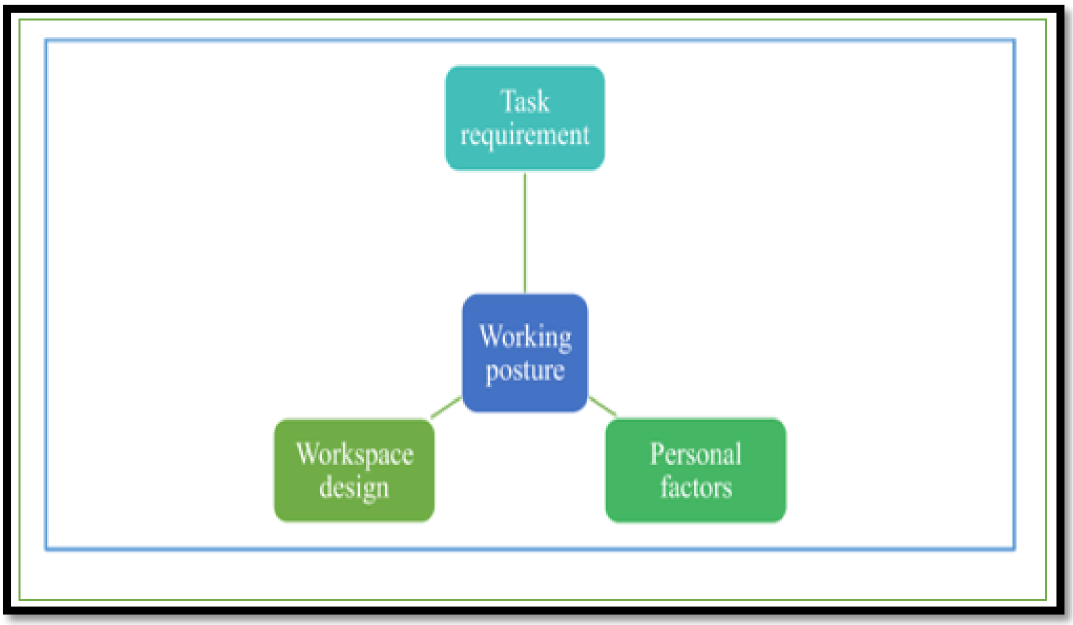


Figure 2.3: Postural triangle

2.3.17.2.1 Use of Anthropometric Data in the Workstation Design

The anthropometric data in the Middle East generally, and in Egypt specifically, possess unique attributes that must be considered when designing an ergonomic workstation (Eladly et al., 2020). According to M. Ali, et al, (2014), the primary purpose of ergonomic principles is to create a workstation that achieves an appropriate balance between workers' anthropometric data and workstation dimensions. The anthropometric data serve as the foundation for designing an ergonomically fitted workstation. Typically, designers, engineers, and economists need to apply the anthropometric data effectively so that at least 90% of users can comfortably use the workstation furniture. Furthermore, to address specific workstation design challenges, three general principles must be taken into account: designing for the extreme individual, designing for the adjustable range, and designing for the average worker, which are discussed in detail below (Ahmed, 2018):

2.3.17.2.1.1 Designing for Extreme Individuals

Designing for extreme individuals is an effective strategy, as utilising the maximum (high) anthropometric data values can accommodate all users. Conversely, designing for the minimum population value is a suitable approach when the minimum (low) anthropometric values are considered to accommodate all users. According to a study by Esmaeel et al., (2020), (2022), for seat depth (SD) design, the 5^{th} percentile of buttock-popliteal length (BPL) population distribution is recommended to accommodate all users, as illustrated in Figure 2.4 (2). Furthermore, for seat width (SW) design, the 95^{th} percentile of hip breadth (HB) population distribution is utilised to accommodate all users, as shown in Figure 2.4 (3).

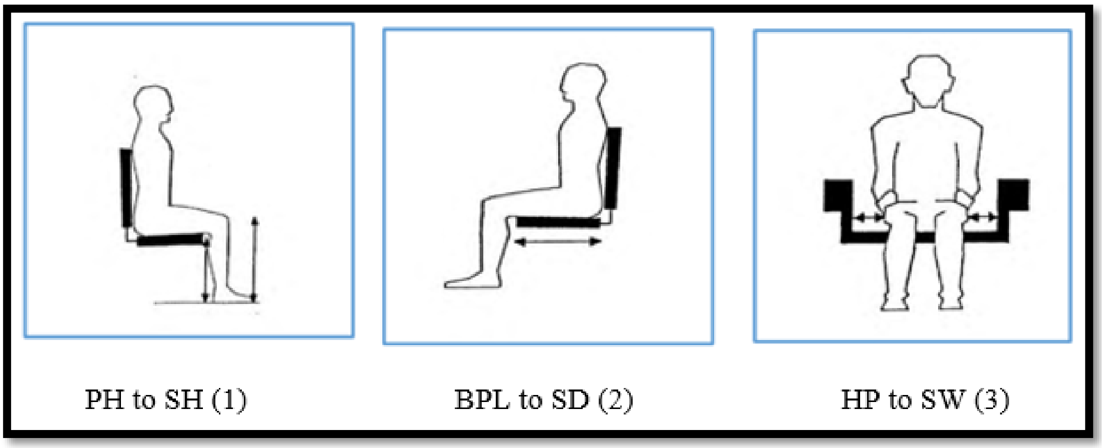


Figure 2.4: Designing for extreme individuals

Source: (Ahmed, 2018).

2.3.17.2.1.2 Designing for Adjustable Range

The design of the adjustable range is an effective strategy if the critical dimensions can be adjusted by all users themselves. In the seated work task, the seat height (SH) and table height (TH) are critical dimensions that should be adjustable by all users. The SH should not be lower than the popliteal height (PH). Furthermore, the TH must align with the sitting elbow height (EH). Additionally, when designing workstation furniture that requires adjustment, it is standard practice to provide adjustments that accommodate the range from the 5th percentile female to the 95th percentile male of the relevant population characteristics. Consequently, the SH is recommended to have an adjustable range from the 5th percentile female to the 95th percentile male PH, as indicated in the population distribution to accommodate all users. See Figure 2.4 (1) mentioned above.

2.3.17.2.1.3 Designing for Average

An individual can be average in one or two dimensions. Designers and engineers often design for the average as a compromise, as they do not have to deal with anthropometric data.

2.3.17.2.2 Designing of Workstations

The normal and maximum work areas for seated workers are zones where they can effectively minimise wasted motion, reduce searching, and maintain a rhythm in their work environments. The normal task area is defined as the space that can be comfortably reached with the sweep of the forearm while the upper arm hangs naturally at the side, while the maximum task area encompasses the reach achieved by extending the arm from the shoulder. General guidelines for workstation design include: positioning materials and tools as close as possible within the operator's normal working area; arranging materials and tools in the order they are used on the assembly line; utilising gravity whenever possible to facilitate the movement of raw materials to the operator and to the next workstation; designing the workstation height and other dimensions to maximise operator comfort; and incorporating foot pedals whenever feasible (Deschênes, 2017).

2.3.17.2.3 Science of Seating in Workstation

The people spend a major portion of their time sitting at the office, workstation, in transport, or elsewhere. Additionally, any inappropriate design of the workstation may affect people's performance and can also contribute to backaches and other back problems. The workstation should provide the utmost comfort to all users after sitting for a few hours. Furthermore, when designing a proper workstation, the following aspects of seating parameters need to be considered (Ahmed, 2018):

2.3.17.2.3.1 Promoting Lumbar Lordosis

Whenever standing in an erect position, the lumbar portion of the spine (the small of the back, just above the buttock) is obviously curved inward (concave), a condition known as lordosis. Conversely, when one is seated with the thighs at a 90^0 angle, the lumbar area of the back levels out and may even adopt an outward curve (convex), resulting in kyphosis. This occurs because the hips rotate only at 60^0, forcing the pelvis to tilt backward around the 30-degree mark to achieve the 90^0 thigh angle. Furthermore, lumbar kyphosis may increase pressure on the discs situated between the vertebrae of the spine. A previous study by Michael et al., (2007) recommended using a forward-tilting chair to prevent flattening or kyphosis of the lumbar spine. Earlier research by Bendix, (1984) suggested that the chair should be tilted from 50^0 backward to 10^0 forward above the transverse axis. The forward-tilted chair should alleviate lumbar symptoms in the lumbar region, and a slanted task surface angled between 10^0 to 15^0 toward the user may enhance the benefits of forward tilting while reducing trunk and neck flexion in individuals engaged in sedentary work. This should decrease the visual angle and promote a more upright trunk posture (Bridger, 1988).

2.3.17.2.3.2 Minimising Disc Pressure

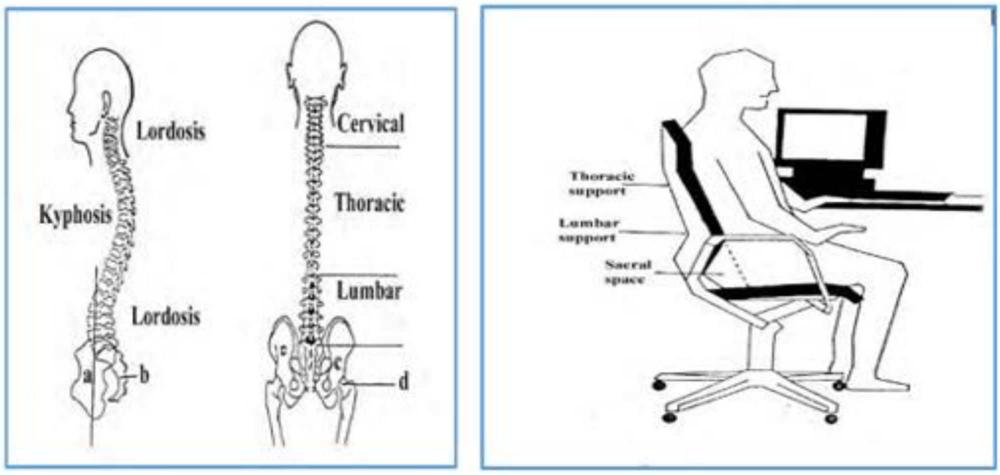
The disc pressure between the vertebrae may be compromised due to excessive disc pressure and an unsupported sitting posture. For instance, not utilising a backrest can significantly elevate disc pressure compared to standing. Furthermore, an unsupported erect sitting posture, such as forced lordosis, may increase disc pressure by 40% compared to standing, while unsupported sitting in a forward slumped posture can raise disc pressure by 90% compared to standing. Several factors can help reduce disc pressure, including the use of a reclined backrest, which has a notable effect on alleviating pressure on the discs.

2.3.17.2.3.3 Minimising Static Loading of the Back Muscles

The muscular activities, as measured by electromyography (EMG), are similar whether standing or sitting, and the EMG activities decrease when a person adopts a forward slumped posture. A reduction in muscular activity in the back occurs when the backrest is reclined up to 110^0, indicating a slight increase in relaxation. Additionally, the effects of lumbar support on EMG activities have shown mixed results.

2.3.17.2.3.4 Reducing Postural Fixity

Postural fixity is defined as maintaining a sitting or standing position for extended periods without significant postural movement. The human body is not designed to remain in one position for long durations. Additionally, the intervertebral discs rely on changes in pressure to obtain nutrients and eliminate waste, as they lack a direct blood supply; fluid exchange occurs through osmotic body pressure. Prolonged sitting or standing in a fixed posture can diminish nutritional exchanges and may lead to degenerative changes in the discs. This postural fixity results in static loading on the back and shoulders, potentially causing pain, while also restricting blood flow to the legs, which can lead to discomfort and swelling. Chairs that accommodate a variety of human postures may help reduce both back and MSDs and postural fixity, as illustrated in Figure 2.5 (a and b). Therefore, prolonged sitting and standing are generally discouraged to mitigate postural fixity.



(a) Lumbar, thoracic cervical spines. (b) Chair with lumber and thoracic support.

Figure 2.5: Reducing the postural fixity

Source: (Ahmed, 2018).

2.3.17.2.4 Ergonomically Design Workstation

The reduction of postural strain or stress is fundamental to ergonomic workstation design, and a multifaceted approach is typically required to create ergonomic workstations for different workers. A study by Deschênes, (2017) suggested that task areas should be considered when designing ergonomic workstations to minimise workers' wasted motion. Recommendations by Arezes et al., (2015) and other scholars, such as Imberg Et Al., (2015); Fulder Et Al., (2005); Hambali Et Al., (2021); Kaya, (2015) also emphasise the importance of considering task areas in ergonomic workstation design. Similarly, Scott & Erin (2006) highlighted that the Business and Institutional Furniture Manufacturers Association (BIFMA) ergonomic guidelines and ergonomic design principles must be taken into account when designing workstations for workers.

2.3.18 Workstation Furniture Prototype Testing

The primary goal and achievement of the previous study was to attain high customer satisfaction through the realisation of ergonomically derived comforts and the application of product design methodology (research papers ergonomic based design and survey, 2014). The study's recommendations suggested that such designs could be implemented in various industries and could be further enhanced with aesthetic modifications, including motivational colours and images. A prior study by Gross et al., (2011) emphasised that when designing a chair for workers, it is crucial to ensure that the chair accommodates the user's body and maintains a comfortable posture, with the feet typically resting on the floor. Moreover, when designing products in a virtual environment, it is easy to lose track of scale, resulting in products that are either too large or too small. Before any actual production, professionals often create a full-sized cardboard mock-up of a product to confirm that the proportions are accurate; however, constructing a full-sized prototype of a designed chair can be challenging for novices. Research by Fulton & Marsh, (2000) indicated that later in the design process, prototypes will be subjected to evaluation in user tests. According to Nadadur & Parkinson, (2013), one method for incorporating comfort considerations is to develop an experimental design model based on the observed interactions of a sample population of users with the product prototypes.

2.4 Simulating the Workstations

2.4.1 Manikin Simulation

In ergonomics and human-factor engineering, the term model is often defined as a representation, as well as a mathematical or physical system that adheres to specific conditions and rules, whose behavior is utilised to understand a real (physical, human-technical, biological, etc.) system that shares certain similarities with the current system. A previous study by Harari et al., (2017) indicated that it focused on multi-objective optimisation and manikin simulation to develop an optimisation process for workstation design that considers both ergonomic and production measures. According to Blanchonette, (2010), when evaluating workstation design, human factors (ergonomics) practitioners have traditionally employed various approaches. Moreover, during the initial stages of the design process, workstation design could be assessed using 3D drafting mannequins. Furthermore, at a later stage in the design process, a prototype of the workstation could be constructed, and the design would be evaluated using anthropometric data models and ″live″ test subjects.

In the early years of the 1960s, 3D computer-aided design (CAD) engineering and simulation software became more accessible. Additionally, aerospace and automotive industrialists recognised the potential for more design processes to occur in a virtual environment. This recognition led to the emergence of tools aimed at accelerating the design process while optimising the human-digital machine interface and digital human modeling in the late 1960s. Today, 3D CAD human digital modeling software is widely utilised in engineering, automotive, and manufacturing machining industries. As noted by Rana et al., (2020), virtual ergonomics (human factors) and digital human models (DHM) have rapidly become significant technologies in workstation design among various applications.

2.4.2 Overview of Ergonomics Simulation for Rapid Upper Limb Assessment (RULA) Test

The RULA analysis was conducted on three different chair models to identify ergonomically suitable options for Indian users. This task can be expanded by manufacturing and fabricating the proposed model, followed by validating the design through experimental work. According to a previous study by Rana et al., (2020), several studies in the literature focus on postural body analysis using ergonomic assessment methods such as the RULA analysis (Mahantesh et al., 2023). Additionally, a prior study by Mohamad et al., (2013) indicated that the working body posture was developed and reconstructed using the Computer-Aided Three-dimensional Interactive Application (CASSIA V5) software, after which the RULA assessment was performed. The RULA analysis revealed several awkward postures that posed high risk factors and hazards. The risky body postures include postures 1, 2, and 5, which primarily involve lifting heavy products and excessive bending. In conclusion, this scholar noted that the RULA assessment successfully identified problematic postures, and further improvements could be implemented to mitigate discomfort or prevent additional health issues.

According to the study by Ansari & Sheikh, (2014), the assessment using postural analysis, such as RULA analysis, indicates that workers are often operating above safe limits. A significant percentage of workers exhibit awkward postures, placing them at moderate to high risk of MSDs. Research by Levanon et al., (2014) found the RULA method to be valid for evaluating computer workers, with one observation being sufficient to assess work-related risk factors. According to the study by Upasana & Vinay, (2017), the results of the postural analysis using the RULA method indicate that over 58%, 60%, and 65% of respondents were at high risk while performing stitching, ironing, and cutting activities at their workstations. A previous study by Mohamad et al., (2013) noted that the RULA analysis is a subjective method for analysing human body posture, focusing on the upper extremities, particularly the trunk, neck, and upper limbs. Research by Marshall & Armstrong, (2004) stated that among the more established methods for evaluating extreme and awkward human body postures are the OWAS and RULA

2.4.3 The Software Packages for Achieving the RULA Analysis Test

The common 3D human digital modeling software is now widely utilised in the defense, manufacturing, and automotive industries, including: The Computer-Aided Three-dimensional Interactive Application (CATIA), JACK, Realistic Anthropological Mathematical System for Interior Simulation (RAMSIS), SafeWork, System for Aiding Man-Machine Interactive Evaluation (SAMMIE), Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) and 3D Static Strength Prediction Program (3DSSPP) (Nadadur & Parkinson, (2013) and Rana et al., (2020). Additionally, at the higher end of the market, a variety of powerful and costly human digital modeling tools are now available (Blanchonette, 2010):

2.4.3.1 Computer-Aided Three-dimensional Interactive Application (CATIA)

To evaluate the human digital model in a virtual environment using digital human modeling as a CAD software like CATIA (Submitted et al., 2015), the study by Latinovic et al., (2015) generated a 3D model using the CATIA V5 software to animate and simulate the models. According to Hambali et al., (2019) the CATIA V5 software is used for the human digital model (HDM) development and the DELMIA V5 is used to simulate product design.

2.4.3.2 JACK human digital modeling tool

The JACK human digital modeling tool (initially called tempus software) was developed at the Center for Human Digital Modeling and Simulation at the University of Pennsylvania in the mid-1980s by a team led by Dr. Dr. Norman Badler. The primary impetus for the development of JACK software was to support the design and development of workstations, with an emphasis on optimising the human-machine interface. Funding for the development of JACK software came from various sources, including significant support from NASA and the United States Army. Furthermore, JACK software is commonly used across a wide range of manufacturing industries by companies and organisations such as John Deere, BAe Systems, NASA and the US Army.

2.4.3.3 Realistic Anthropological Mathematical System for Interior Simulation (RAMSIS)

The RAMSIS model was developed in the late 1980s as a cooperative effort between German automobile manufactures Tecmath and the Technical University of Munich, Germany. RAMSES is widely used in the automotive manufacturing industry for designing vehicle interiors and exteriors by many companies, including Audi, Volkswagen, Daewoo, Ford, Honda, Mazda and Renault. Additionally, the Australian automotive industry and Ford Australia have utilised RAMSES for several years.

2.4.3.4 SafeWork Software

The SafeWork software is extensively utilised in the automotive, manufacturing, and defense sectors by various companies, including General Dynamics, Daimler Chrysler and Boeing, along with government organisations such as Defense Research and

Development Canada. SafeWork was originally developed at Ecole Polytechnique, Canada during the 1980s and is currently being advanced by Dassault Systemes.

2.4.3.5 System for Aiding Man-Machine Interactive Evaluation (SAMMIE)

The SAMMIE model was initially developed at the University of Nottingham and later at Loughborough University. It has been applied to a wide variety of the problems across numerous fields, including tram driver workstations, aircraft cockpit design, and more.

2.4.3.6 Digital Enterprise Lean Manufacturing Interactive Application (DELMIA)

The DELMIA human work task simulation is a robust tool designed to create, validate, and simulate worker activities using the Digital Process for Manufacture (DPM) planning and simulation infrastructure. Workers perform these activities within a workstation environment, where they can navigate to specific locations, ascend and descend stairs, transition between various body postures, climb ladders, follow the trajectories of kinematic devices or object paths, and automatically grasp, pick, and place parts in the work area. Users can also establish part relationships to constrain specific segments of the worker to the parts and tools in the garment environment (Dassault Systemes, 2008a). Position constraints are stored from the selected segments to the chosen 3D objects in the garment environment or the standard V5 catalogs. These constraints are subsequently resolved to update the human body posture for the next instance, modifying the activity accordingly. DELMIA’s virtual ergonomics can be integrated with DELMIA’s DPM assembly to analyse the relationships between workers and other entities within the simulation object. They can also be simulated and validated using powerful process simulation tools and capabilities within the DPM.

This allows users to test and optimise multiple alternatives for tasks that must be accomplished in specific manufacturing, maintainability, and assembly environments (Dassault Systemes, 2008b).

2.4.3.7 3D Static Strength Prediction Program (3DSSPP)

The 3DSSPP software predicts the static strength required for tasks such as pressing, lifting, pushing, and pulling. The program offers an estimated job simulation that incorporates human body posture data, force parameters, and male or female anthropometric data. The DHMs are rapidly becoming an effective tool for conducting proactive ergonomics design and analysis. DHM software, such as: The JACK, SafeWork, RAMSIS, SAMMIE and the 3DSSP, is designed to assist designers early in the product development process, particularly when they are working to improve the physical design of vehicle interiors and manufacturing workstations (3D Static Strength Prediction Program, (1996). These tools, as previously mentioned, feature human models (manikins) with complex kinematic linkages that closely resemble the human skeletal structure, joints that adhere to physiological motion limits, and a geometric shell that accurately reflects the human shape.

The models of the human body (manikins) can be developed based on recent comprehensive civilian and military anthropometric surveys. The SafeWork software accommodates over 100 anthropometric variables, including buttock-knee length, foot length, stature, and span (Chaffin, 2007). The workspace software can be created and modified using a variety of native modeling tools along with libraries of standard objects, such as workstation furniture. Additionally, the workspace software can be imported from third-party software packages. A range of human body factors analysis equipment is available to support workstation assessment. For instance, reach envelopes can be created, and collision detection algorithms may be employed to determine if a task was completed safely (Chaffin, 2007).

2.4.4 Finite Element Analysis (FEA)

2.4.4.1 The FEA Overview

The FEA is a numerical analysis method used to address challenges in various engineering fields, including machine design, acoustics, electromagnetism, fluid dynamics, soil mechanics, and more. Mathematically, FEA is a numerical technique employed to solve numerous field problems represented by a set of partial difference equations. In mechanical engineering, FEA is extensively utilised for resolving structural, thermal, and vibration issues. While FEA is a prominent tool for numerical analysis, other methods such as the finite difference technique, boundary element technique, and finite volume technique also exist. Due to its versatility and numerical efficiency, FEA has come to dominate engineering analysis within the CAD software market. Other methods have been relegated to niche applications; when integrated into modern marketable 3D software, both FEA theory and the numerical problem formulation become entirely transparent to the user (Mahantesh et al., 2023).

The FEA is a reliable numerical method for analysing engineering designs, transforming a complex problem into several simpler ones. According to Mod & As (2021a), the FEA is a numerical technique for addressing issues in mathematical physics and engineering design. It is particularly useful for tackling problems with intricate geometries, material properties, and loadings where analytical solutions may not be feasible. The FEA employs virtual simulation technology to assess how a product design responds to physical effects, including vibration, bending, fluid flow, heat, and other impacts. According to Madara et al., (2016), the FEA is a computational technique used to derive estimated solutions for boundary or field value problems in engineering design. The FEA was selected as one of the best tools for this study because it enables us to identify the optimal design with a high degree of confidence. An earlier study by Haraga & Goantă, (2017) noted that the FEA is a significant computerised numerical technique that provides approximate solutions for structural and thermal analysis across various application areas. Additionally, a previous study by Mahantesh et al., (2023) stated that the FEA is a numerical tool used to analyse physical phenomena in fluid and solid mechanics, as well as in the structural field, and is employed for solving boundary problems. In the workstation furniture industry, the FEA is utilised to determine strength, equivalent stress, and total deformation.

A previous study by Sciences, (2014) observed that the finite element models produced exhibited values close to the actual behavior of chair frames. Furthermore, the highest strains and deformations occurred in models lacking a stretcher. Therefore, the use of stretchers is expected to decrease the deformation and strains of chair frames under loads, consequently reducing material consumption in workstation manufacturing. According to Mustafa (2012) in the literature review, the first research on the FEA in workstation furniture design dates back to 1966. A previous study by Haraga & Goantă, (2017) focused on the FEA in a multi-functional armchair, which had the following main specific objectives: to select eco-friendly materials commonly used in furniture manufacturing; to implement adaptive mesh refinement; to visualise the results of structural analysis; to reduce the global error rate; and to provide reasonable estimates. Current research by Ceylan et al., (2021) aimed to provide significant information about the cyclic loading performance of wooden chairs and to demonstrate the application of structural analyses through the FEA in workstation furniture manufacturing. According to previous research by Mahantesh et al., (2023), the FEA was conducted on three different chair models to achieve an ergonomically suitable chair for Indian users.

2.4.4.2 Finite Element Analysis (FEA) Used by Design Engineers

The FEA is a powerful engineering analytical tool useful for solving a range of problems, from the very simple to the highly complex. Additionally, design engineers utilise the FEA during the workstation product development process to analyse the design in progress. The time constraints and limited availability of workstation product data necessitate numerous simplifications of the computer models. Conversely, specialised analysts employ the FEA to tackle intricate problems, such as vehicle crash dynamics, airbag deployment, and hydroforming. Moreover, modern design is conducted using SolidWorks, making the model the starting point for FEA analysis. Since the models describe the geometric information for the FEA, it is essential to understand how to prepare the model geometry to produce accurate FEA results and how these models differ from the FEA models. Meanwhile, the FEA is a design engineering tool that should be used concurrently with the design engineering process. It should also drive the design engineering process rather than follow it (Mahantesh et al., 2023).

2.4.4.3 Objectives of the Finite Element Analysis (FEA) for the Design Engineers

The ultimate goal of utilising the FEA as a design engineering tool is to transform the design engineering process from repetitive cycles of design, prototyping, and testing into a streamlined process where prototypes are not employed as design engineering tools and are only required for final design validation. Additionally, with the implementation of the FEA, design engineering iterations are shifted from the physical realm of prototyping and testing to the virtual domain of computer engineering simulations, as illustrated in Figure 2.6. Furthermore, traditional product development relies on prototypes to support ongoing design engineering. In simulation-driven product development, numerical models are used instead of physical prototypes to guide the development. Whenever a simulation FEA is influenced by the product design engineering process, the prototype is not included as part of the iterative design engineering loop (Haraga & Goantă, (2017).

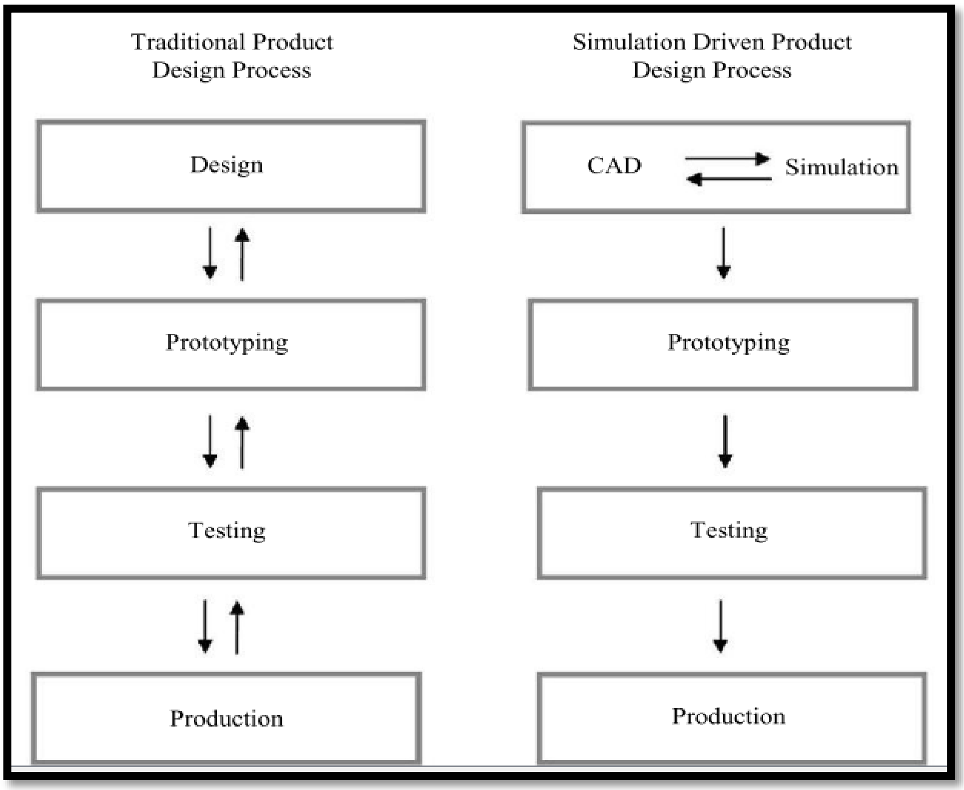


Figure 2.6: Traditional and simulation driven product development

2.4.4.4 Limitations of the Finite Element Analysis (FEA) for Design Engineers

A clear question arises: Would it be better to have a dedicated specialist perform the FEA while allowing designers and engineers to focus on what they do best for new product designs? The answer depends on the size of the business, company organisation, products, culture, and many other tangible and intangible factors. Furthermore, there is a general consensus that design engineers can handle relatively simple types of analysis, but they should do so quickly and reliably. Moreover, analyses that are very complex and time-consuming cannot be executed alongside the design engineering process. These are often better managed by a dedicated analyst and/or contracted out to specialist consultants (Haraga & Goantă, 2017).

2.5 Optimising Workstations

2.5.1 An Overview of Optimisations

Optimisation plays a crucial role in both design and mechanical engineering. An optimisation process assists designers and engineers in meeting technical requirements while reducing material and industrial costs (Tien et al., 2021). Furthermore, traditional automatic structures are often optimised based on experimental results. In this manner, a design must be fabricated and tested multiple times to identify the optimal configuration for the workstation. This leads to increased costs and extends the design time needed to develop a new product, potentially causing a company to fall behind in the market race. Additionally, a previous study by Scurtu et al., (2015) indicated that various engineering design optimisation methods have been explored, which can be utilised to create the optimal design of workstation furniture based on existing requirements.

2.5.2 Designing Optimisation

The FEA packages are primarily parametric and include components such as the airfare intercostal, webs, ribs, etc. Additionally, the design can be modeled using the variables. Geometrical shape optimisation can be achieved with FEA, which is very useful in reducing the number of iterations needed for an optimal design and minimising engineering design hours. Strength and stiffness optimisation can also be performed through FEA packages, which can decrease the overall weight of a furniture structure (Javidinejad & Ph, 2021).

2.5.3 Optimisation Analysis

The optimisation analysis automates the search for the optimal design. Additionally, the SolidWorks simulation software enables designers and engieers to vary a single design variable to identify the best solution for that specific criterion. SolidWorks also offers further optimisation capabilities such as (Systemes, 2021):

2.5.3.1 The Manual Process

In the quest for the optimal design, it is necessary to manually test various dimensions, geometric configurations, materials, loads, and fixtures. Each time a change is made, designers and engineers must rerun the study and analyse the results (Systemes, 2021).

2.5.3.2 The Automated Process

The optimisation analysis automates the manual procedure for the specific configuration (Systemes, 2021). Trends can be detected swiftly, allowing for the identification of the optimal solution in the fewest number of test runs. Furthermore, the optimisation analysis requires the following inputs, as shown in Table 2.4 below:

Table 2.4: Requires for optimisation analysis (Systemes, 2021)

Objective	**States the objective, or goals, for example, the designer/engineer should specify minimum material.**
Design Variables or Geometry Constraints	Selects the dimensions, or variables, that can change and set their ranges. For example, the designer/engineer specify that the diameter of a hole can vary from 0.5 inch to 1.0 inch while the extrusion of a sketch can vary from 2.0 inch to 3.0 inch.
Behavior Constraints	Sets the conditions, or constraints, that the optimum design must satisfy. For example, the designer/engineer specify that stresses, displacements, temperatures should not exceed certain values and the natural frequency should be in a specified range.

2.5.3.3 The Output

The output of the SolidWorks simulation aims to identify the optimal solution that meets the geometric and behavioral constraints (Systemes, 2021).

2.6 Fabricating Workstations

2.6.1 Overview of Workstation Furniture Manufacturing Systems

In general, workstation furniture encompasses both decorative art and design. Beyond its utilitarian role, workstation furniture has also served a symbolic and religious purpose in human civilisation. It is crafted from various types of materials, and its construction has evolved from primitive tools to techniques based on woodworking joints that reflect local culture and the craftsman's skills. In the early days, manufacturing workstation furniture was time-consuming, as craftsmen transformed ideas into tangible products using rudimentary tools (Bambura et al., 2020; Miller, 1989; and Ratnasingam, et al., 2020). Research by Miller, (1989) indicated that the industrial revolution, marked by the advent of electric power and mechanical wood processing technology, prompted the evolution of workstation furniture manufacturing to keep pace with advancements. Furthermore, power tools and machines were integrated into the manufacturing processes, and the craftsman’s skills were surpassed by the precision and speed of technology. However, many woodworking mechanisms were adapted from the principles of metalworking machines. Nonetheless, this adaptation completely revolutionised workstation furniture and the woodworking industry.

According to Ratnasingam et al., (1999), the advent of machine woodworking led to improved design and manufacturing productivity in the workstation furniture and wood-based manufacturing industry. Two important characteristics of machine woodworking applications are faster production rates and increased machining accuracy, which skilled craftsmen had not been able to achieve, particularly for repetitive operations. Previous studies by Ratnasingam, (2022) and Simek & Sebera, (2010) indicate that the introduction of information and computer technology into the workstation furniture and woodworking industries further revolutionised the sector. Additionally, a previous study by Zhao & Li, (2014) stated that the combination of these technologies enabled manufacturers to enhance their design and manufacturing processes to levels of speed and accuracy that had not been reached before.

Furthermore, SolidWorks software is a powerful tool that enables designers and engineers to visualise, improvise, and modify designs quickly on computer screens. Additionally, it allows for the depiction of workstation furniture designs, significantly enhancing design ideation and product development. The improved clarity of design ideas, along with the ability to rotate, modify, and render colours swiftly, means that the lead time for workstation product development is significantly reduced. Moreover, the CAD software enhances creativity, speed, precision, and accuracy in product development while lowering costs (Kaprol, 2016; Miller, 1989; Das, 1996; Ratnasingam et al., 2020; Eyers & Potter, 2017; Koren et al., 2017; Csanády et al., 2019; Release, 2011; Mohammadi et al., 2020; Quesada & Gazo, 2006).

Research by Gawroński, (2013) stated that the interface between computers and machines through computer languages, such as G-codes and M-codes, resulted in computer-controlled machines. For instance, the Computer Numerical Controlled (CNC) routers, guided by CAD data, perform machining operations with high precision and quality finishes. The CNC workstations have replaced humans in several repetitive tasks across numerous industries and allow a variety of machining operations to be executed with quick automated tool changes. The CNC router easily machines mechanisms and decorative parts for workstation furniture once the desired shapes and dimensional data are programmed into the computer. According to Yao & Carlson, (2003), workstation furniture manufacturing systems have correspondingly evolved over time. Moreover, traditional craftsmanship has been supplanted by technology to facilitate mass production systems. These mass production systems were simplified by machine technology, enabling furniture products to be manufactured in large quantities with minimal diversity. The manufacturing flow is continuous, where every workstation and operation on the product is carried out as it moves along the line until completion, as seen in Figure 2.7.

According to a previous study by Mohammadi et al., (2020), as the demand for product diversity increased—particularly in fashion-sensitive items such as workstation furniture—the batch production system evolved. This system is characterised by small production quantities alongside greater product diversity. Furthermore, with the advent of Industry 4.0 nearly a decade ago, the batch size-1 production system was introduced in the furniture manufacturing sector. Batch size-1 production represents a fundamentally different model from traditional mass production. As batch sizes decrease, machines must become more flexible and intelligent. Manufacturers need to adapt their equipment, methods, and planning for workstation furniture production.

A study by Hunter, (2008) highlights that, despite the constant availability of technological advancements in the marketplace, one aspect of the production system is occasionally tailored to meet individual customer requirements for unique workstation furniture pieces. For example, replicating antique workstation furniture using exceptional raw materials is essential to create a one-of-a-kind replica of the highest quality. Craftsmanship, aesthetic appeal, and the expertise of master craftsmen are indispensable in this process. Furthermore, such a production system remains rare due to the scarcity of master craftsmen and the high costs involved.

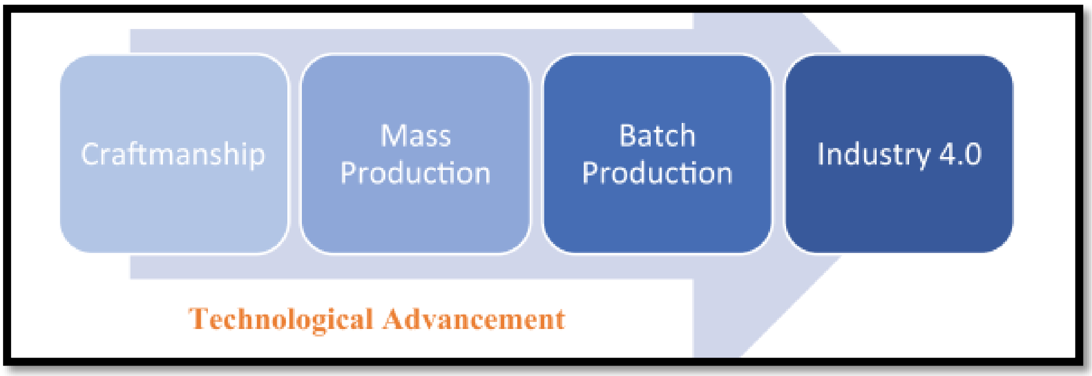


Figure 2.7: Evolution of the workstation furniture production system

2.6.2 Workstation Furniture Design Process

Workstation furniture design is the process of conceptualising a new product that can be manufactured and sold to customers. The ideas generated through a market-sensitive thinking process often lead to the development of innovative workstation furniture products (Miller, 1989; and Ratnasingam et al., 2019). Figures 2.8 and 2.9 illustrate the various steps involved in the workstation furniture design process. Moreover, the scope of innovations within the workstation furniture industry is relatively limited, with most sources of innovation being external. It must be emphasised that without innovation, the opportunity to advance further along the value chain diminishes. Workstation furniture designers conceptualise and evaluate ideas, transforming them into tangible inventions and novel products (Kanduč & Rodič, 2015, Desch & Dinwoodie, 1996, Stokke, 2013, Zhao et al., 2022, Musgraves et al., 2019, Ratnasingam & Scholz, 2004, Huang & Intarakumnerd, 2019; Xu et al., 2015, Ratnasingam, (2022, Ciupan et al., 2018, Staneva et al., 2018; Dutta & Sharma, 2023, Csanády et al., 2019, and Kumar, 2018).

In the previous research by Xiong et al., (2017), it was stated that the role of workstation furniture designers is to blend science, art, and technology to create innovative workstation furniture products for users. Additionally, their evolving role has been enhanced by advancements in digital tools and technology, which now enable workstation furniture designers to visualise, communicate, analyse, create 3D models, conduct rapid prototyping, utilise 3D printing, and analyse big data to predict consumer behavior. Furthermore, these advancements have significantly reduced the lead time from design concepts to tangible prototypes.

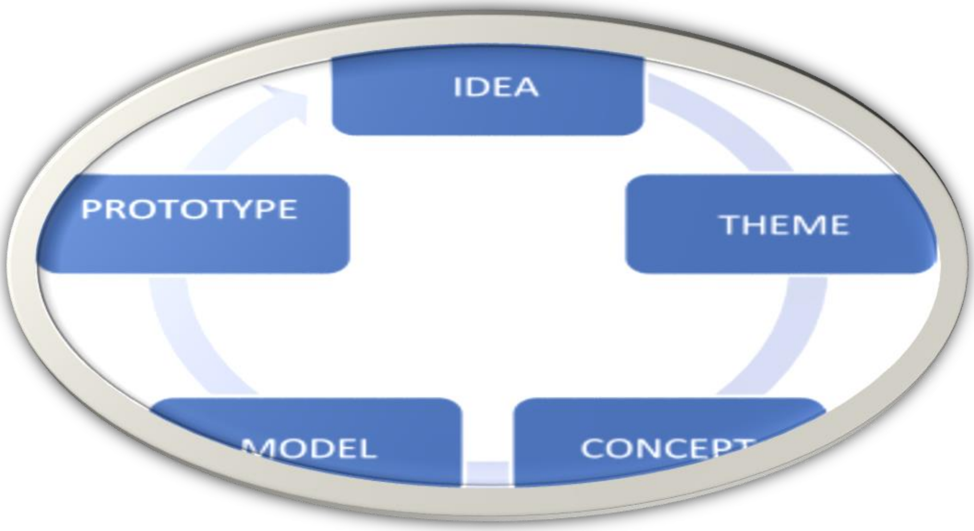


Figure 2.8: Workstation Furniture Design Ideation Process

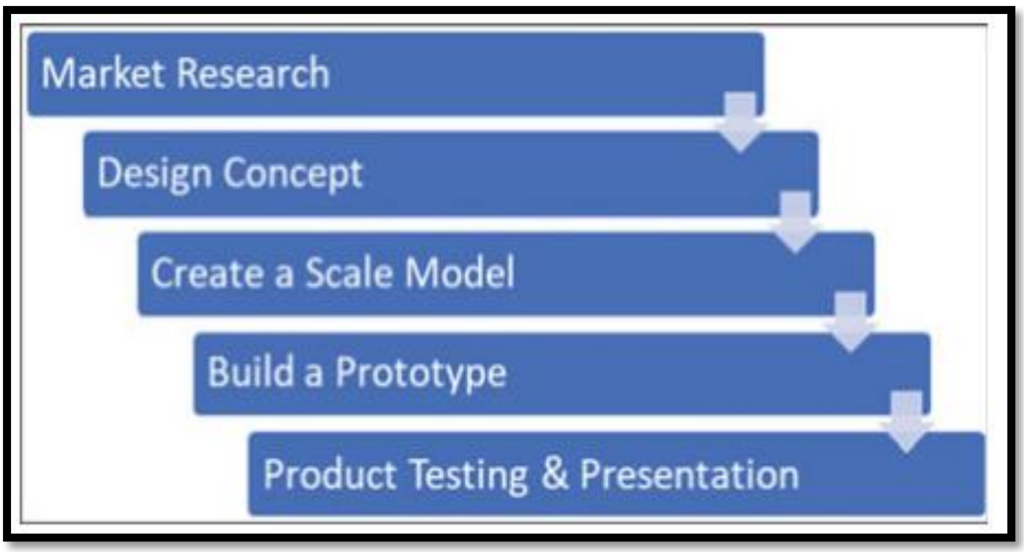


Figure 2.9: Workstation furniture design process

2.7 Research Gaps

Limited to the aforementioned literature review, previous researchers Al-Hinai et al., (2018) recommended that the compatibility between workstation dimensions and workers' anthropometric characteristics is a key factor in enhancing workers' physical responses. Additionally, numerous researchers worldwide, including Chung & Wong, (2007), Milanese & Grimmer, (2004), Saarni et al., (2007, Castellucci et al., (2015), Dianat et al., (2013), Gopura & Amarasena, (2008), and Taifa & Desai, (2017), have confirmed a clear mismatch between workers' anthropometric characteristics and workstation dimensions. The design of workstations in the garment industry often lacks adequate consideration of anthropometric measurements. This mismatch can lead to MSDs and negatively impact working efficiency due to prolonged sitting in uncomfortable positions. Furthermore, ergonomically redesigned workstations are known to reduce MSDs and enhance the motivation of garment workers in their work environment. This research will address existing gaps by establishing an ergonomic redesign of sewing workstations for garment manufacturing based on selected anthropometric data at REAL, Eldoret, Kenya. This will ensure comfort, safety, adaptability, and suitability, improve productivity, and ultimately guarantee user satisfaction while reducing MSDs and work-related risks and hazards.

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

This third chapter of the current thesis discusses the methods employed to achieve the objectives of this research. Furthermore, the experimental section can be detailed according to the specific objectives in the following sub-sections, as illustrated in Figure 3.1.

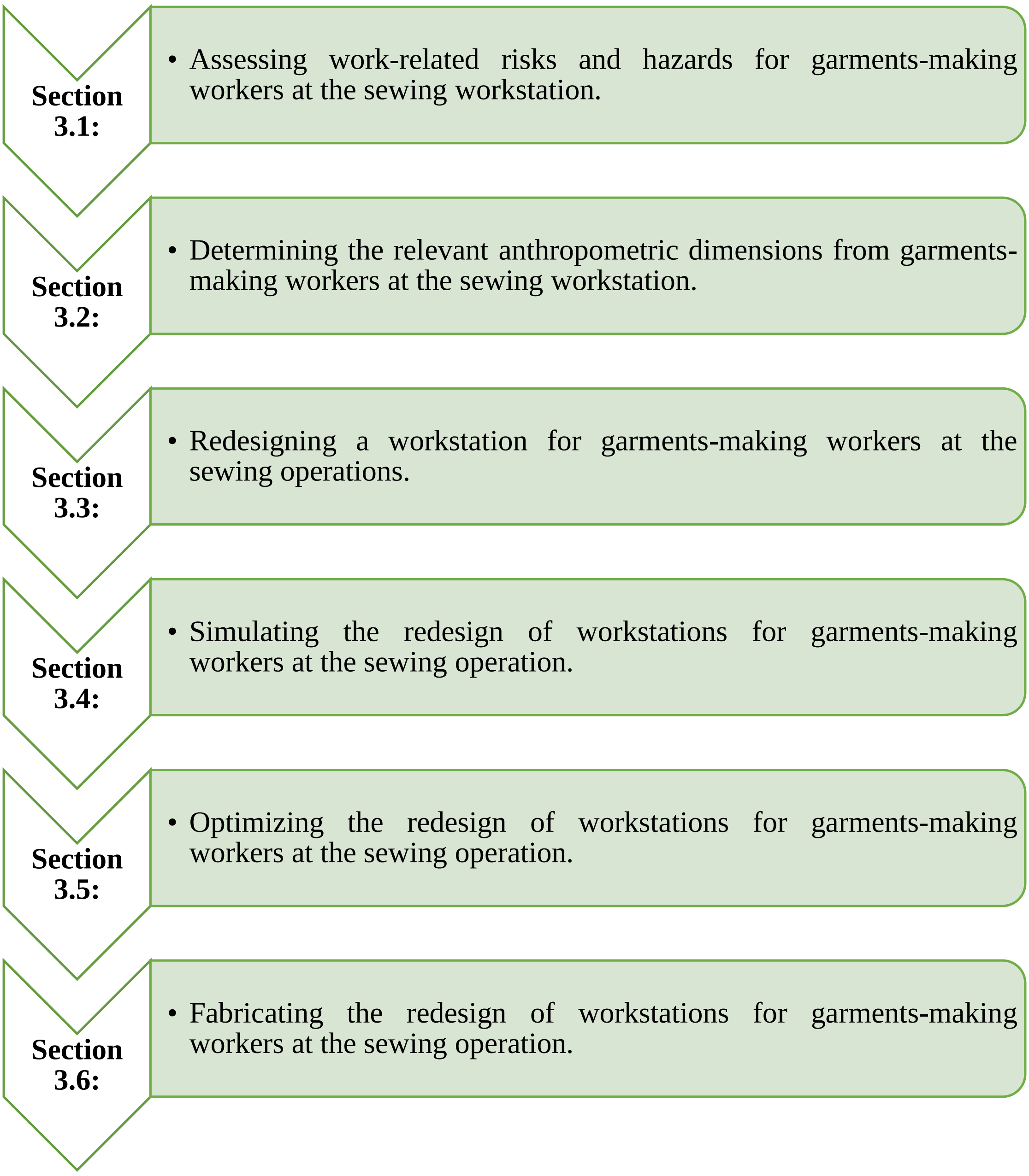


Figure 3.1: Sub-sections of the research methodology

3.1 Assessing Work-Related Risks and Hazards for Garments-Making Workers at the Sewing Workstation

3.1.1 Introduction

The Rapid Entire Body Assessment (REBA) serves as a comfort analysis tool and a means to evaluate the risk of Work-Related Musculoskeletal Disorders (WRMSDs). Furthermore, to assess the ergonomics of a sewing workstation, it is essential to understand the characteristics of the worker who will be using it. To achieve the first specific objective of this research, the entire methodology can be outlined in the following section:

3.1.2 Rapid Entire Body Assessment (REBA) Procedure Methodology

Assessment utilising the Rapid Entire Body Assessment (REBA) method has been carried out by Dr. Hignett and Dr. Mcatamney through multiple stages, as illustrated in Figure 3.2 (Kusuma, 2020; Wibowo & Mawadati, 2021):

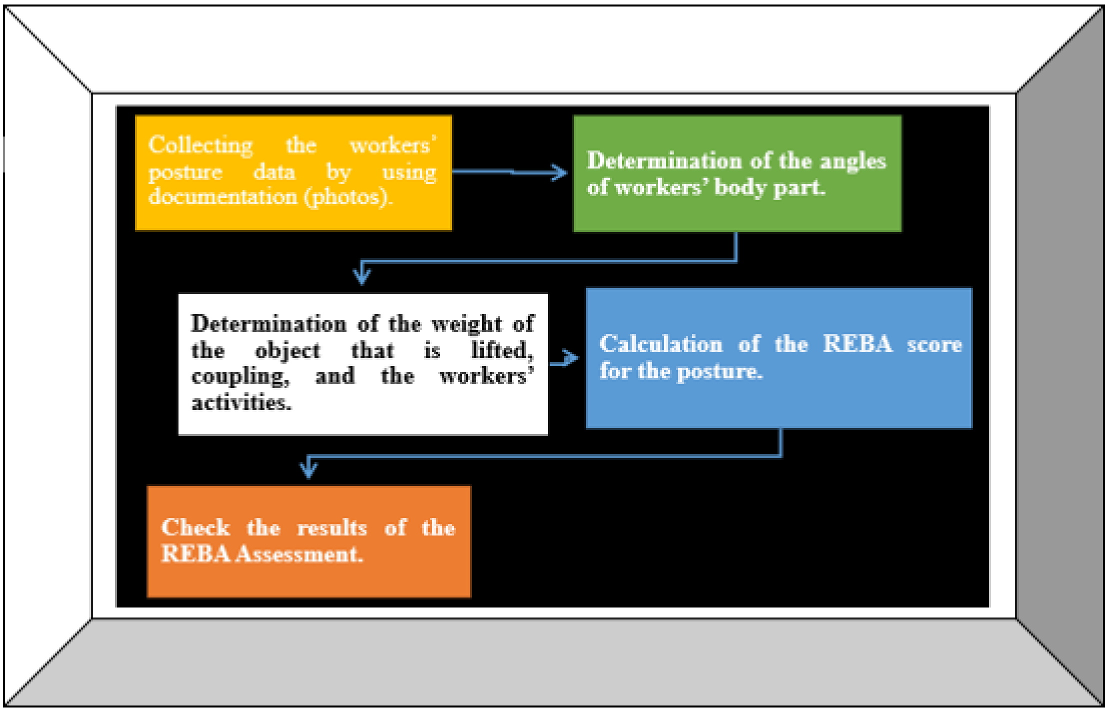


Figure 3.2: Rapid Entire Body Assessment (REBA) procedure methodology

3.1.2.1 Collecting the Workers' Posture Data Using Documentation (Photos)

To obtain a detailed description of the workers' attitude (posture) and their neck, back, arms, wrists, and feet. The recorded photos involve using a camera and/or camcorder to capture images of the worker and the equipment utilised by them. Furthermore, in order for the researcher to effectively assess combined movement, the photo analysis should be conducted at a 90^0 angle to the subject. Thus, the manual goniometer can be used most efficiently. This allows the researchers to break down the procedure step by step. Additionally, it was carried out by documenting the workers' body posture (photos) as illustrated in Figure 3.3. Consequently, the researcher obtains detailed (valid) body posture data from the recorded photos, as well as accurate data from the calculation and subsequent analysis stages. The photos can also be utilised to ensure that the angles to be measured appear in accurate magnitude in the images.

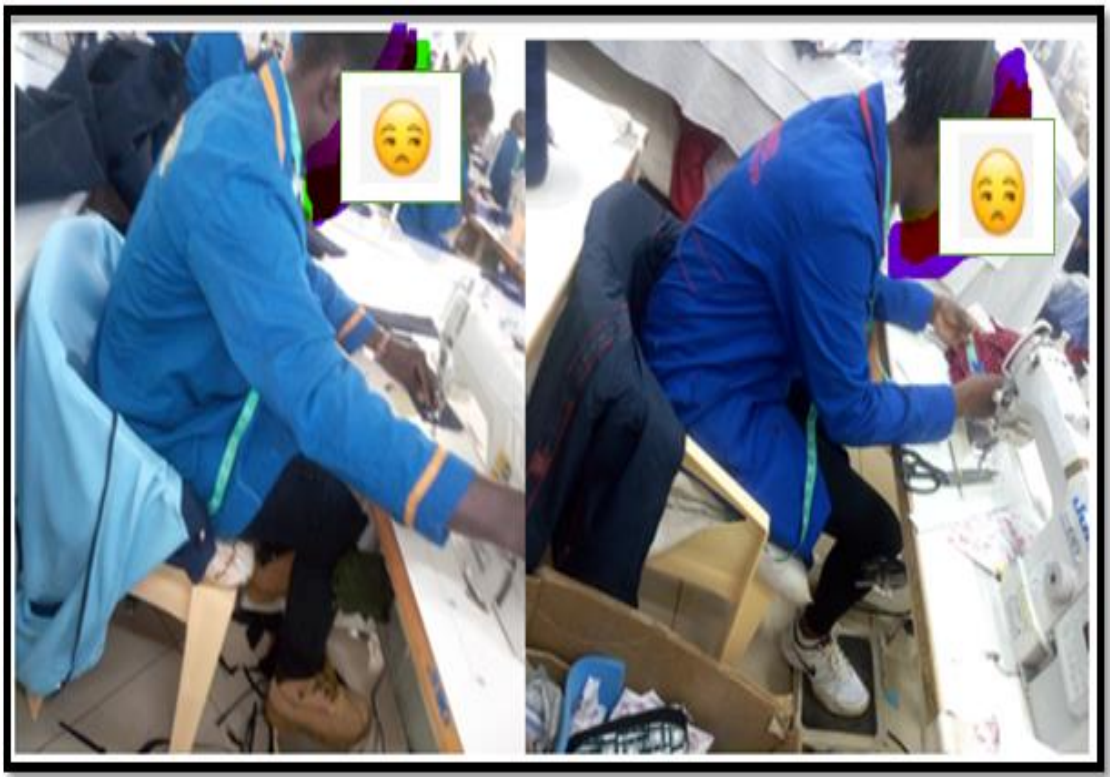


Figure 3.3: Postures adopted during working at the existing sewing workstation

3.1.2.2 Determination of the Angles of the Workers' Body Part

After recording the photos of the workers' postures, the angles of each body segment were calculated, including the back, neck, upper arms, forearms, wrists, and feet. Additionally, in the implemented REBA method, the body segments were divided into two groups: group A and group B. Group A consists of the back, neck, and knee, while group B includes the upper arms, lower arm, and wrist. Furthermore, based on the angle data of the body segments in each group, the scores for group A and group B can be found in Tables 3.1 and 3.2, as well as in Figure 3.4, referencing the REBA employee assessment worksheet.

Table 3.1: Determination of the angles of the workers' body part (Group A)

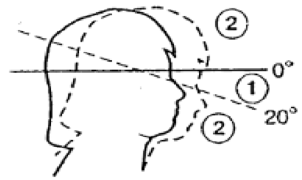
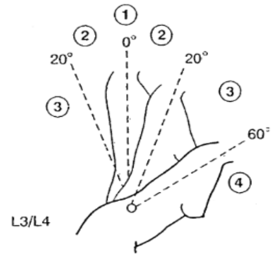
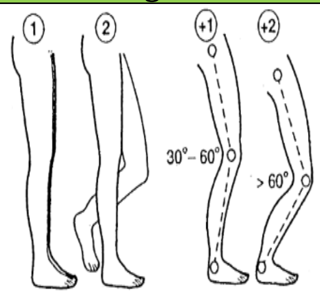
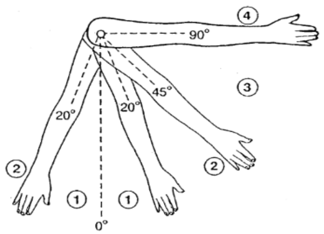
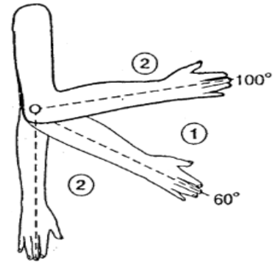
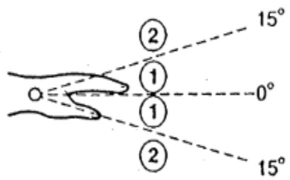
The score of neck movement				
Movement	**Score**	**Change score**	**Figure**	**Reference**
$0^0 – 20^0$ flexion	1	+1 if twisting or side flexed		Beatrix, (2021).
> 20 flexion or in extension	2			
The score of back movement				
Movement	**Score**	**Change score**	**Figure**	**Reference**
Straight/natural/upright	1	+1 if twisting or side flexed		McAtamney & Hignett, (2004).
$0^0 – 20^0$ flexion	2			
$0^0 – 20^0$ extension				
20 – 60 flexion	3			
$\geq 20^0$ extension				
$> 60^0$ flexion	4			
The score of knee movement				
Movement	**Score**	**Change score**	**Figure**	**Reference**
The feet is supported, the load is uniformly distributed, walking or sitting	1	+1 if the knee(s) between 30^0 and 60^0 flexion.		Wibowo & Mawadati, (2021).
The feet is supported, the load is not uniformly distributed, and the body posture is unstable.	2	2+ if the knee(s) are $> 60^0$ flexion.		

Table 3.2: Determination of the angles of the workers' body part (Group B)

The score of upper arm movement				
Movement	**Score**	**Change score**	**Figure**	**Reference**
20^0 extension to 20^0 flexion.	1	+1 if the position of the arm is abducted or rotated		Fan et al., (2022), Kusuma, (2020), and McAtamney & Hignett, (2000).
> 20^0 extension and/or $20^0 – 45^0$ flexion.	2	+1 if the shoulder is raised		
$45^0 – 90^0$ flexion.	3	-1 if leaning, supporting weight of arm or if body posture is gravity assisted		
> 90^0 flexion.	4			
The score of lower arms movement				
Movement	**Score**	**Change score**	**Figure**	**References**
$60^0 – 100^0$ flexion.	1	No change should be done.		McAtamney & Hignett, (2004), and Wibowo & Mawadati, (2021).
< 60^0 flexion or > 100^0 flexion.	2			
The score of wrists movement				
Movement	**Score**	**Change score**	**Figure**	**Reference**
$0^0 – 15^0$ flexion / extension.	1	+1 if wrists are deviated or twisted.		McAtamney & Hignett, (2000).
> 15^0 flexion / extension.	2			

3.1.2.3 Determination of the Weight of the Object that is Lifted, Coupling and the Workers' Activities

To calculate the score for each body segment, several additional factors must be considered, including the weight lifted, coupling, and the workers' activities. Furthermore, each of these factors has its own scoring category, as illustrated in Table 3.3 and Figure 3.4.

Table 3.3: Determination of the weight, coupling and the workers' activities

Load/force			
Weight		**Score**	**Reference**
< 5 kg		0	Wibowo & Mawadati, (2021).
5 – 10 kg		1	
> 10 kg		2	
Shock or rapid build-up of force		+1	
Table coupling			
Coupling score		**Action**	**Reference**
0	Good	Well-fitting handle and a mid-range-power grip.	McAtamney & Hignett, (2004).
1	Fair	Hand hold acceptable, but not ideal; or coupling is acceptable via another part of the body.	
2	Poor	Hand hold not acceptable, although possible.	
3	Unacceptable	Coupling is unacceptable if using other parts of the body.	
Activity Score			
Activity description		**Score**	**Reference**
One or more parts are static, e.g., holding more than 1 minute.		+1	Ansari & Sheikh, (2014).
Repeated small range action, e.g., repeated more than 4 times per minute.		+1	
Action cause rapid large range changes in postures or an unstable base.		+1	

3.1.2.4 Calculation of the REBA Score for Posture

After obtaining the scores from Table A, they should be added to the weight of the load lifted, resulting in the part A score. Meanwhile, the scores obtained from Table B should be combined with the score from the coupling Table, leading to the part B score. Additionally, part A and part B scores are used to calculate the part C score based on Table C. Furthermore, the final REBA score is derived from the sum of the part C scores and the scores of the workers' activities. See Table 3.4 and Figure 3.4.

Table 3.4: Calculation of the REBA score for posture (Middlesworth, 2014)

Table A

	Neck											
	1				2*				3			
Back / **Knee**	1	2	3	4	1	2*	3	4	1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	5	6
2*	2	3	4	5	3	4*	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Table B

	Lower arm					
	1			2*		
Upper arm / **Wrist**	1	2	3	1	2*	3
1	1	2	2	1	2	3
2*	1	2	3	2	3*	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Table C

		Score B											
		1	2	3*	4	5	6	7	8	9	10	11	12
Score A	1	1	1	1	2	3	3	4	5	6	7	7	7
	2	1	2	2	3	4	4	5	6	6	7	7	8
	3	2	3	3	3	4	5	6	7	7	8	8	8
	4*	3	4	4*	4	5	6	7	8	8	9	9	9
	5	4	4	4	5	6	7	8	8	9	9	9	9
	6	6	6	6	7	8	8	9	9	10	10	10	10
	7	7	7	7	8	9	9	9	10	10	11	11	11
	8	8	8	8	9	10	10	10	10	10	11	11	11
	9	9	9	9	10	10	10	11	11	11	12	12	12
	10	10	10	10	11	11	11	11	12	12	12	12	12
	11	11	11	11	11	12	12	12	12	12	12	12	12
	12	12	12	12	12	12	12	12	12	12	12	12	12

3.1.2.5 Check the Results of the REBA

The final score of the REBA is categorised into five degrees of ergonomic risk severity: score 1 indicates negligible risk, with no action necessary; scores 2 to 3 represent low risk, suggesting that changes may be needed; scores 4 to 7 indicate medium risk, requiring changes soon; scores 8 to 10 signify high risk, necessitating investigation and implementation soon; and score 11 denotes very high risk, demanding immediate change. Based on the required level of action, it is evident that addressing the risk levels associated with muscles and actions is essential to reduce the risk of work-related injuries and enhance work quality. Additionally, the application of the REBA method and the corresponding risk levels can be found in Table 3.5 and Figure 3.4, referencing the REBA employee assessment worksheet.

Table 3.5: REBA action level

REBA level	REBA score	Risk level	Action description	References
0	1	Negligible	None necessary.	Fan et al., (2022), Hignett & McAtamney, (2000), Kusuma, (2020), and Sheba et al., (2009).
1	2 – 3	Low	May be necessary.	
2	4 – 7	Medium	Necessary.	
3	8 – 10	High	Necessary soon.	
4	11+	Very high	Necessary now.	

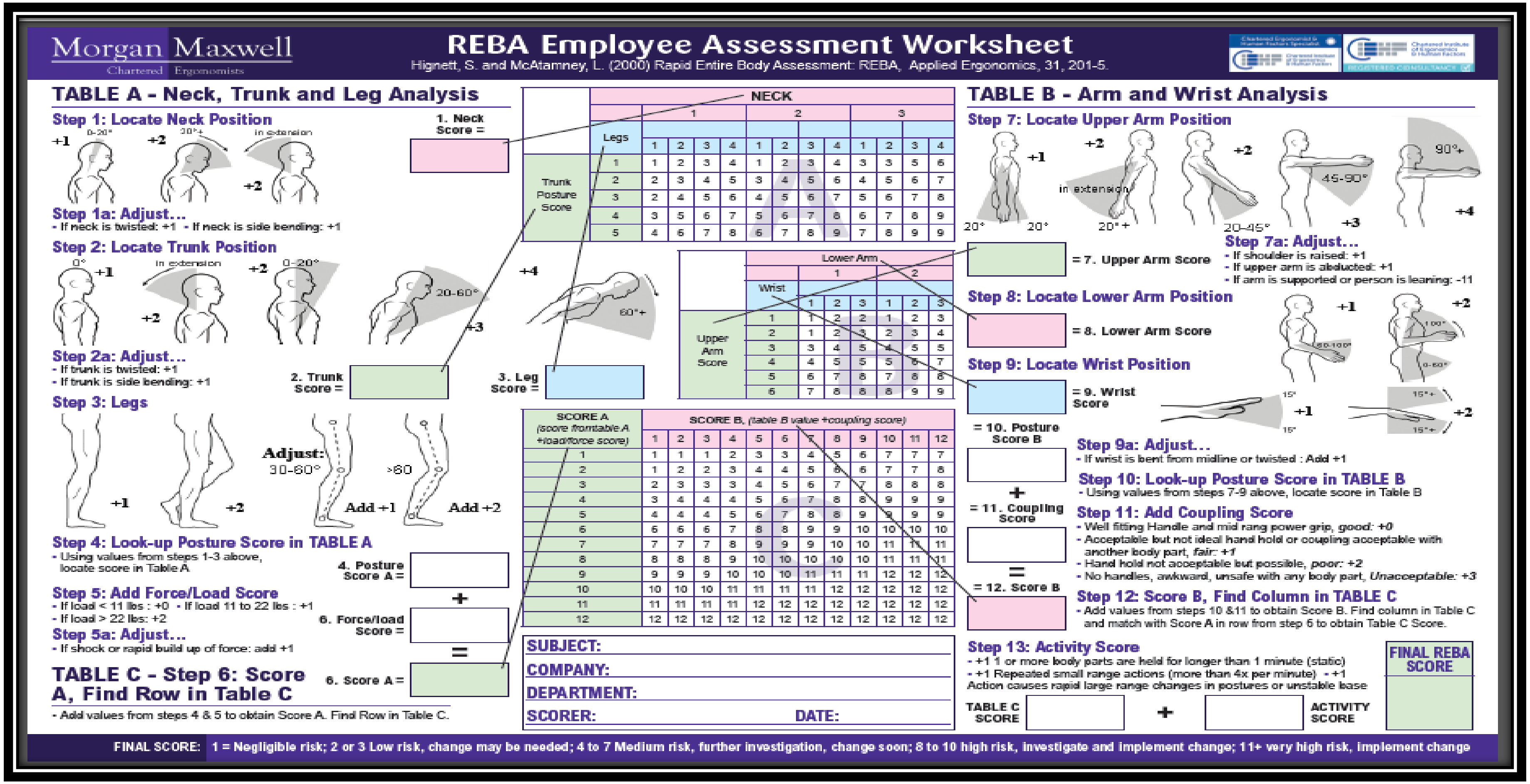


Figure 3.4: REBA Employee Assessment Worksheet

Source: (Mcatamney & Hignett, 2000; Middlesworth, 2014).

3.2 Determining the Relevant Anthropometric Dimensions from Garments-Making Workers at the Sewing Workstation

3.2.1 Introduction

To determine the relevant anthropometric measurements for the workers from REAL, Eldest, Kenya, is the second specific objective of this research. Anthropometric data was collected from garment workers. Additionally, eleven anthropometric measurements (sitting height, shoulder height sitting, popliteal height sitting, elbow height sitting, buttock popliteal length, buttock knee length, thigh clearance, eye height sitting, knee height sitting, forearm fingertip length, and hip breadth sitting) were taken from workers using anthropometric tools. This research applied fundamental engineering principles of product design and was conducted in compliance with ISO 7250-1:2017 (Basic human body measurements for technological design part 1: Body measurement definitions and landmarks), which was sourced from the Kenya Bureau of Standards (KEBS) website; see Appendix III for the ISO standard. Furthermore, the anthropometric data from workers was compared using a one-way ANOVA analysis test. Additionally, the data obtained was analysed using Minitab software to determine the mean, standard deviation, minimum, maximum, 5^{th}, 50^{th}, and 95^{th} percentiles. Moreover, to achieve the second specific objective of this research, the entire methodology can be followed using the procedure outlined in Figure 3.5.

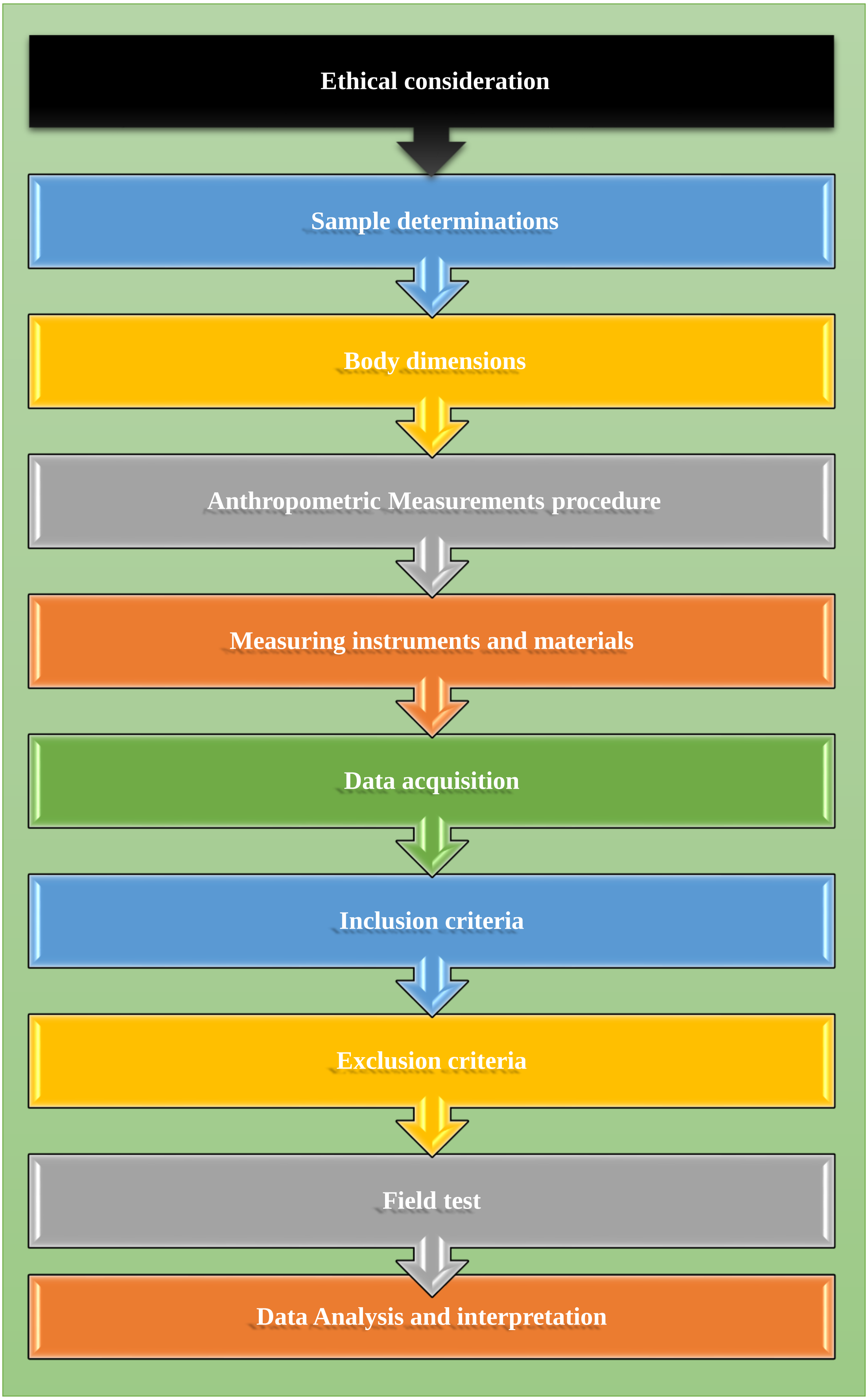


Figure 3.5: Main steps of the anthropometric measurements

3.2.2 Ethical Consideration

An introductory letter from the head of the department was addressed to the managing director of REAL, as seen in Appendix IV, and the REAL factory was approved to engage with the research, as noted in Appendix V. Approval for data collection was obtained from the ethics committee of the National Commission for Science, Technology and Innovation (NACOSTI), Republic of Kenya, as indicated in Appendix VI. Additionally, the roles of the participants in the current research were explained and discussed, along with the fact that the research had received ethical approval and posed no harm to the participants. Furthermore, consent from the workers was obtained prior to the commencement of the measurements, and the participants were informed about the anthropometric measurements, enabling them to understand the study's aims and objectives clearly. The female data was collected in accordance with local cultural practices (a female assistant was hired to measure the female workers).

3.2.3 Sample Determinations

The total number of workers included in this research was one hundred thirty-four (134), comprising both male and female employees from the sewing workstation department at REAL, Eldoret, Kenya. Additionally, the sample size for this study was calculated using equations (3.1) (Madara, 2016; Homkhiew et al., 2012):

$$\text{Sample-size} = \frac{\frac{Z^2 * P\,(1-P)}{e^2}}{1+\frac{Z^2 * P\,(1-P)}{e^2\,N}} \quad \text{(3.1).}$$

Whereby:

N is total number of the workers, which is 134 (both male and female).

Z is the standard normal deviation for a 95% confidence level (the Z-score of 95% is the 1.96), P is the proportion in the target population estimated to possess a particular characteristic. For instance, if P is considered to be 50%, then (1-P) represents the proportion in the target population lacking that characteristics.

e is the margin of error (degree of accuracy) required, typically set at 5% level as established by Homkhiew et al., (2012). To determine the appropriate Z-score, it is advisable to refer to Table 3.6 as well as Figure 3.6.

Table 3.6: The Z-score is based on the desired confidence level

Desired confidence level (%)	Z-score	Reference
80	1.28	Berengolts & Lindenbaum, (2004).
85	1.44	
90	1.65	
95	1.96	
99	2.58	

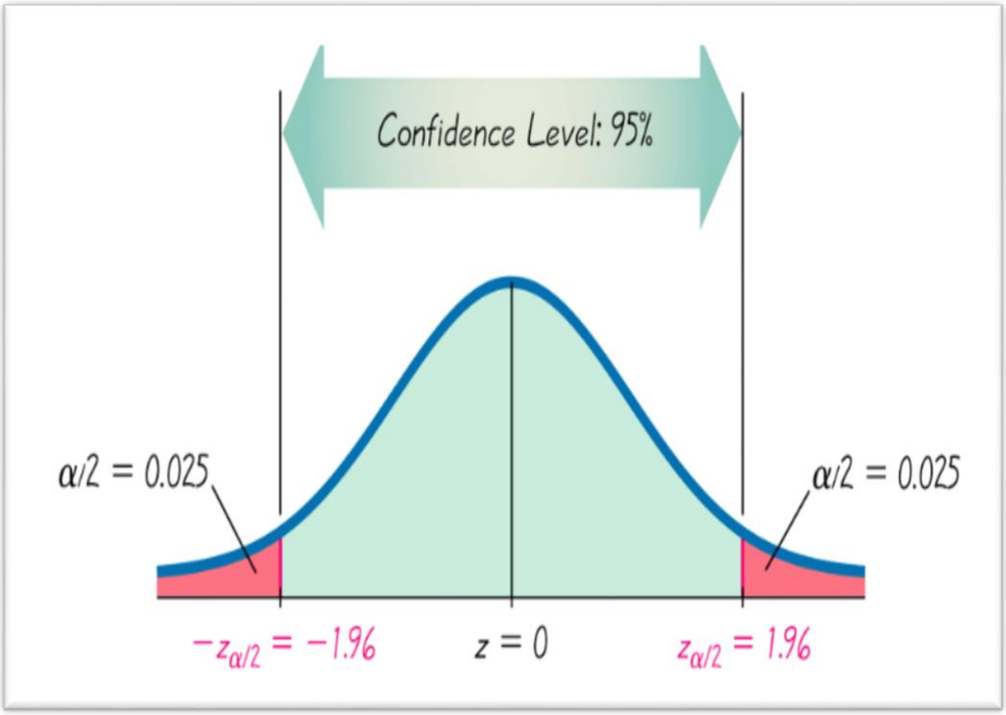


Figure 3.6: Confidence level of 95%

Source: (Berengolts & Lindenbaum, 2004).

The sample size, in this present research was = $\frac{\frac{(1.96)^2 * 0.5\,(1-0.5)}{(0.05)^2}}{1+\frac{(1.96)^2 * 0.5\,(1-0.5)}{(0.05)^2 * 134}}$ = **100**.

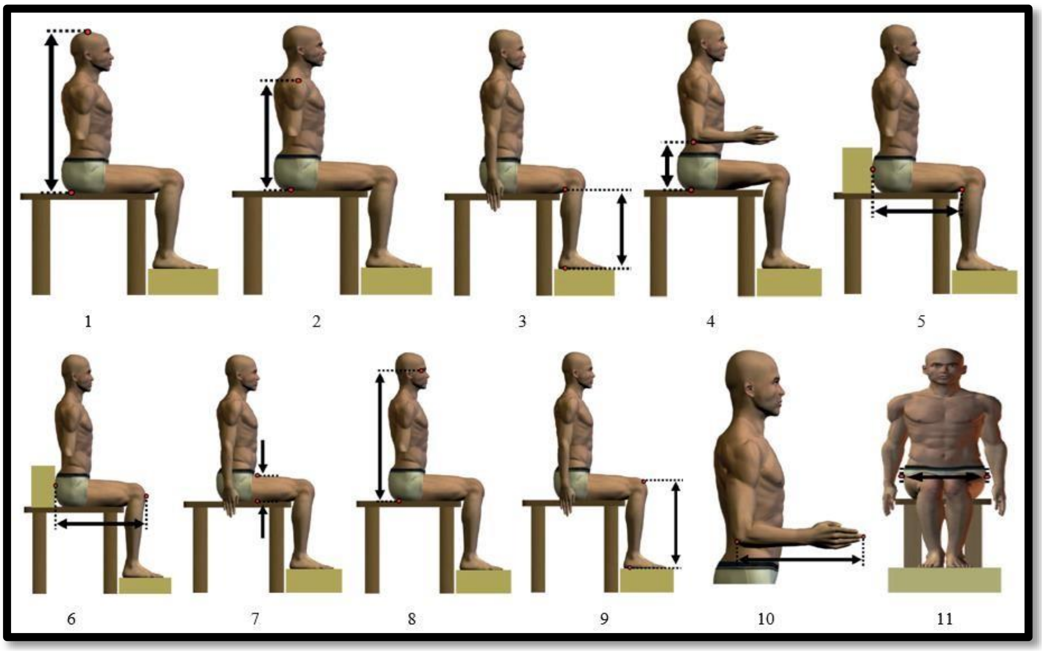
Therefore, the sample size was 100 (50% male and 50% female) workers.

3.2.4 Body Dimensions

Redesigning the sewing workstation requires direct involvement of anthropometric measurements. Various researchers (Habib, 2015; Patil et al., 2017; and Rittel, 2010), suggested that the body dimensions essential for redesigning a sewing workstation, specifically the sewing chair and adjustable sewing machine table for garment-making workers, should be considered. All anthropometric data collected was based on ISO 7250-1:2017. The actual dimensions of the sewing workstation were determined by measurements of the human body. Likewise, the two most relevant anthropometric measurements for the sewing chair redesign are the popliteal height sitting and buttock popliteal length (Esmaeel, 2021). The popliteal height sitting is the distance from the underside of the foot to the underside of the thigh at the knees, and it is sometimes referred to as ″stool height″. The term ″sitting height″ is reserved for the height to the top of the head when seated. Conversely, the popliteal height, after adjusting for heels, clothing, and other factors, is used to determine the height of the sewing chair seat. Similarly, according to Igbokwe et al., (2019), the buttock popliteal length is the horizontal distance from the rearmost part of the buttocks to the back of the lower leg. This anthropometric data was used to determine the seat depth. Based on the ISO 7250-1:2017, therefore, Table 3.7, shows the serial number and descriptions of the selected worker’s body dimensions. Additionally, see Appendix VII for basic workers' body dimensions and their significance. Figure 3.7 illustrates the exact location of all selected eleven anthropometric dimensions.

Table 3.7: Selection of body dimensions to be measured for workstation redesign

No.	S/NO. According to ISO 7250	Basic workers' body dimensions	Description according to ISO 7250-1:2017	Reference
1	6.2.1	Sitting height (erect)	The vertical distance from a horizontal sitting surface to the highest point of the head (vertex).	Esmaeel & Order, (2017)
2	6.2.4	Shoulder height, sitting	The vertical distance from a horizontal sitting surface to the acromion.	
3	6.2.11	Popliteal height, sitting	The vertical distance from the foot-rest surface to the lower surface of the thigh immediately behind the knee bent at right angles.	
4	6.2.5	Elbow height, sitting	The vertical distance from a horizontal sitting surface to the lowest bony point of the elbow bent at a right angle with the forearm horizontal.	
5	6.4.7	Buttock popliteal length (seat depth)	The horizontal distance from the hollow of the knee to the rearmost point of the buttock.	
6	6.4.8	Buttock knee length	The horizontal distance from the foremost point of the knee-cap to the rearmost point of the buttock.	
7	6.2.12	Thigh clearance	The vertical distance from the sitting surface to the highest point on the thigh.	
8	6.2.2	Eye height, sitting	The vertical distance from a horizontal sitting surface to the outer corner of the eye (ectocanthus).	
9	6.2.13	Knee height, sitting	The vertical distance from the floor to the highest point of the superior border of the patella (suprapatella, sitting).	
10	6.4.6	Forearm fingertip length	The horizontal distance from olecranon (back of the elbow) to the tip of the middle finger, with the elbow, bent at right angles.	
11	6.2.10	Hip breadth, sitting	The breadth of the body measured across the widest portion of the hips.	



Keys:

				References
1	Sitting height (erect)	7	Thigh clearance	Kapuria, (2018), Esmaeel & Order, (2017).
2	Shoulder height sitting	8	Eye height, sitting	
3	Popliteal height, sitting	9	Knee height, sitting	
4	Elbow height, sitting	10	Forearm fingertip length	
5	Buttock popliteal length	11	Hip breadth sitting	
6	Buttock knee length			

Figure 3.7: Anthropometric data required in sewing workstation redesign

3.2.5 Anthropometric Measurements Procedure

Anthropometric measurement procedures are (Johan & Renate, 2005; Castellucci et al., 2014): First, before commencing the anthropometric measurements, several activities should be undertaken, such as identifying the target population, defining the sample size, determining the anthropometric data, preparing the assessment team(s), and obtaining approval from the ethics committee. Second, during the anthropometric measurements, it is crucial to adhere to a standard procedure. Third, after collecting the anthropometric measurements, it is essential to verify the data by observing the mean, standard deviation (St. Dev.), minimum (min), maximum (max), 5th, 50th, and 95th percentiles. In general, the sample size was randomly collected from garment workers at REAL, Eldoret, Kenya. Additionally, the body size of each worker was assessed using standard anthropometric measurement techniques, adapted from various researchers' findings on anthropometric body dimensions relevant to the working posture at a workstation. Similarly, measurements were taken from participants at a fixed date and time during their free time. In this research, all dimensions were measured while the workers sat erect on an adjustable desk with their knees bent at 90^0. Each worker was asked to sit at the adjustable desk, which was modified to ensure maximum comfort. Furthermore, all anthropometric measurements were taken from the right side of the subjects while they are seated, with subjects wearing light clothing (shorts and t-shirts) in a relaxed and erect posture, without shoes to ensure quick and accurate measurements of the human body, as illustrated in Figure 3.8. The time required to complete all measurements for each subject was approximately 10 to 15 minutes. Additionally, measurements were taken every working day for 20 days in July 2023. Correspondingly, the workers' measurements were conducted in a quiet area rather than in the sewing department. All anthropometric measurements were recorded in centimeters (cm).

Figure 3.8: Measurements in a sitting position

3.2.6 Measuring Instruments and Materials

To measure the various body dimensions of workers, there are several techniques and tools that are commonly used. Some of the methods include: (1) 3D scanners, which are quite expensive and not accessible to all researchers; and (2) traditional anthropometric tools, which are considered simpler, cheaper, and more accessible to many researchers compared to 3D body scanners. Additionally, it is well-known that using standard mechanisms may yield more accurate results. The equipment used in this present research comprises:

1. Anthropometer, which was used to measure, sitting height, elbow height sitting, shoulder height sitting, knee height sitting, popliteal height sitting eye height sitting, buttock popliteal length and buttock knee length as shown in Figures 3.9 (1).
2. Large sliding caliper (Range 0-600 mm with error 0.1 mm), which was used to measure, hip breadth sitting and forearm fingertip length as shown in Figure 3.9 (2).
3. Digital vernier height gauge (with a measuring range of 0-300 mm and resolution of 0.01mm), which was used to measure thigh clearance as shown in Figure 3.9 (3).
4. A metal tape, which was used to measure, sewing furniture dimensions as shown in Figure 3.9 (4). While a Goniometer was used to measure the backrest angles, seat angle and desk angle of the sewing furniture as shown in Figure 3.9 (5).
5. Adjustable desk, which was used to make the subjects sit while measurements were being taken as shown in Figure 3.9 (6).

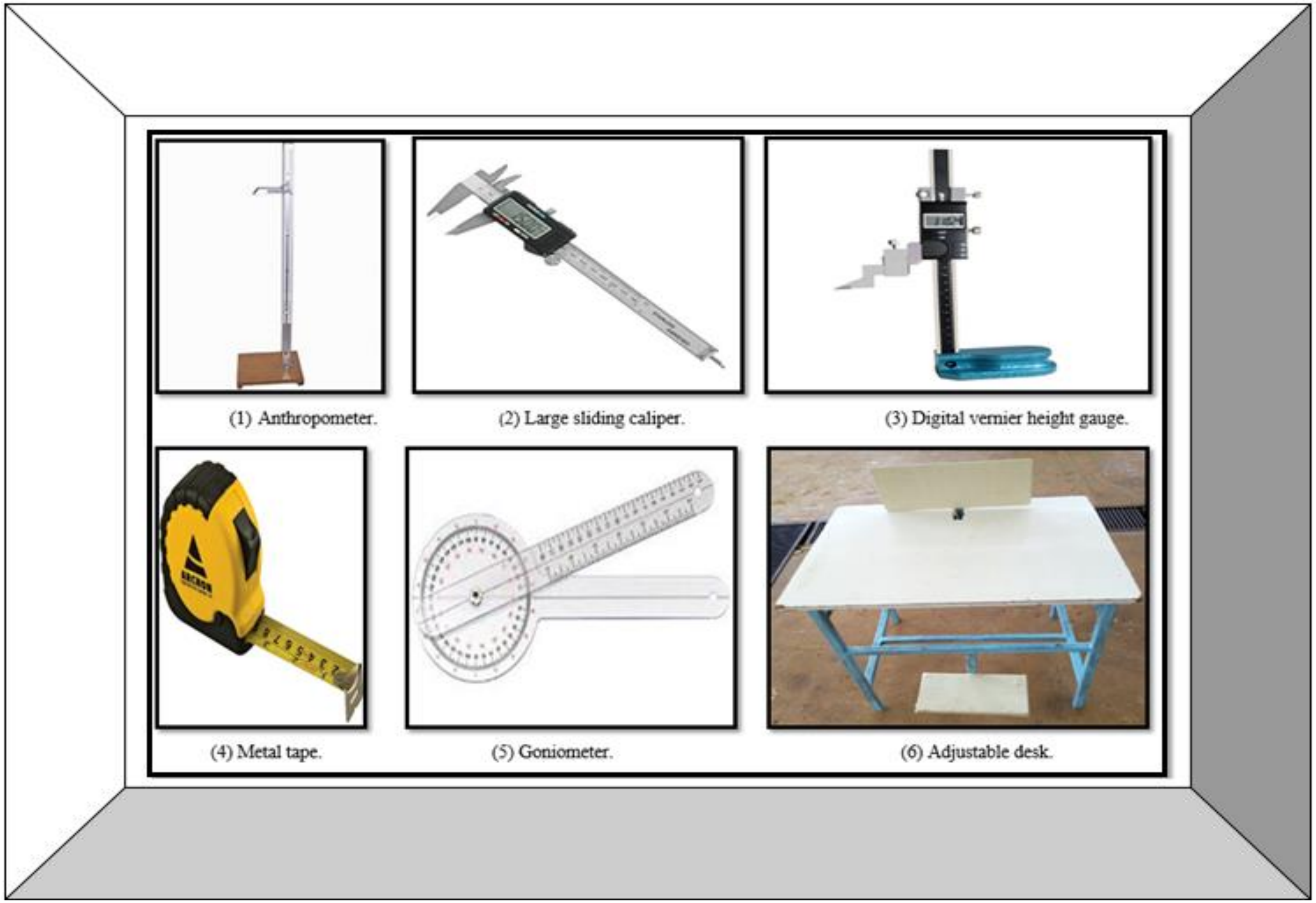


Figure 3.9: Measuring instruments and materials

3.2.7 Data Acquisition

The dimensions measured are documented in a form, see Appendix VIII. Additionally, the form includes personal information such as data number, sex, and department name. Participants were asked to complete the forms with their personal information before the measurement process began. This form also offers spaces for all eleven anthropometric dimensions mentioned above.

3.2.8 Inclusion Criteria

The inclusion criteria for this study are as follows:

- Only garments workers in the sewing department were selected for participation in the study.
- Both males and females.
- Kenyan origin.
- Voluntary participants.

3.2.9 Exclusion Criteria

The following exclusion criteria for this research are:

- Garments workers with fracture or any body deformities were excluded because such conditions could lead to inaccurate data results.
- Pregnant women were excluded from the study due to the various complications they may face related to changes in body structure.

3.2.10 Field Test

Before commencing the final data collection, it was essential to conduct a field test that helped refine the data collection plan. A field test was carried out with ten participants of varying genders who had experience in the sewing workstation department. From the field test, the researcher gained insights into the condition of the area and participant reactions, allowing for assumptions about the data from male and female participants and identifying which parts of the procedure posed difficulties for them. During the field test, the participants were informed about the aims and objectives of the study; they were cooperative and adhered to all instructions properly, resulting in the appropriate collection of data.

3.2.11 Data Analysis and Interpretation

The data recorded was analysed statistically with the help of Minitab 17.0, a statistical package. On the other hand, one-way ANOVA analysis was used to check for any variation in the results achieved. Additionally, the anthropometric data was analysed using mean, standard deviation (SD), minimum (min), maximum (max), 5^{th}, 50^{th}, and 95^{th} percentiles as discussed in detail below:

3.2.11.1 Analysis of Variance (ANOVA) using Minitab 17.0 Software

One-way ANOVA analysis was developed by the English mathematician and statistician R. Fisher (Bower, 2018). Typically, scientists aim to detect differences in means across various levels of a factor or among different groups. For instance, the one-way ANOVA procedure can be demonstrated using the popular statistical software Minitab 17.0. In this research, one-way ANOVA analysis was employed as a statistical technique to compare three or more means. When conducting one-way ANOVA, three key assumptions must be met, as outlined by Altincicek, (2014):

1. The observations are obtained independently and randomly from the populations defined by the factor levels.
2. The population at each factor level is (approximately) normally distributed.
3. These normal populations share a common variance.

3.2.11.2 Mean and Standard Deviation Calculation

Mean and standard deviation calculations for the collected anthropometric data are presented in the following formulas (Kapuria, 2018, and Silviana et al., 2022):

Mean $(\overline{x}) = \frac{\sum_{k}^{n} =1 \, (x_k)}{n}$ ………….. ………….. …………………………… (3.2).

Where,

x Sample

$\overline{x}$ Mean

n No. of sample data

Standard deviation (S) = $\sqrt{\frac{\sum_{k=1}^{n} (x-(\overline{x})}{n-1}}$ …………………………………………… (3.3).

Where,

x Sample

$\overline{x}$ Mean

S Standard deviation

n No. of sample data

3.2.11.3 Calculation Pth Percentiles using Minitab 17.0

The percentile indicates the position of the z-score within a distribution, as illustrated in Table 3.8. Percentiles range from 1 to 99, with anthropometric dimensions for each population typically ranked by size and defined as a percentile (Hse, 2005). Additionally, the percentile is depicted in Figure 3.10 and can be selected from 0.01 to 99.99 ((Of, Process & data, 2019).

Table 3.8: Z-values for normally used percentiles

Percentile	Z-values	Percentile	Z-values	Reference
1st	-2.326	75th	0.675	
2.5th	-1.960	90th	1.282	
5th	-1.645	95th	1.645	http://sphweb.bumc.bu.edu/otlt/
10th	-1.282	97th	1.960	MPHModels/BS/BS704_Probabi
25th	-0.675	99th	2.326	lity/BS704_Probability10.html.
Percentile		**Z-values**		
50th		0		

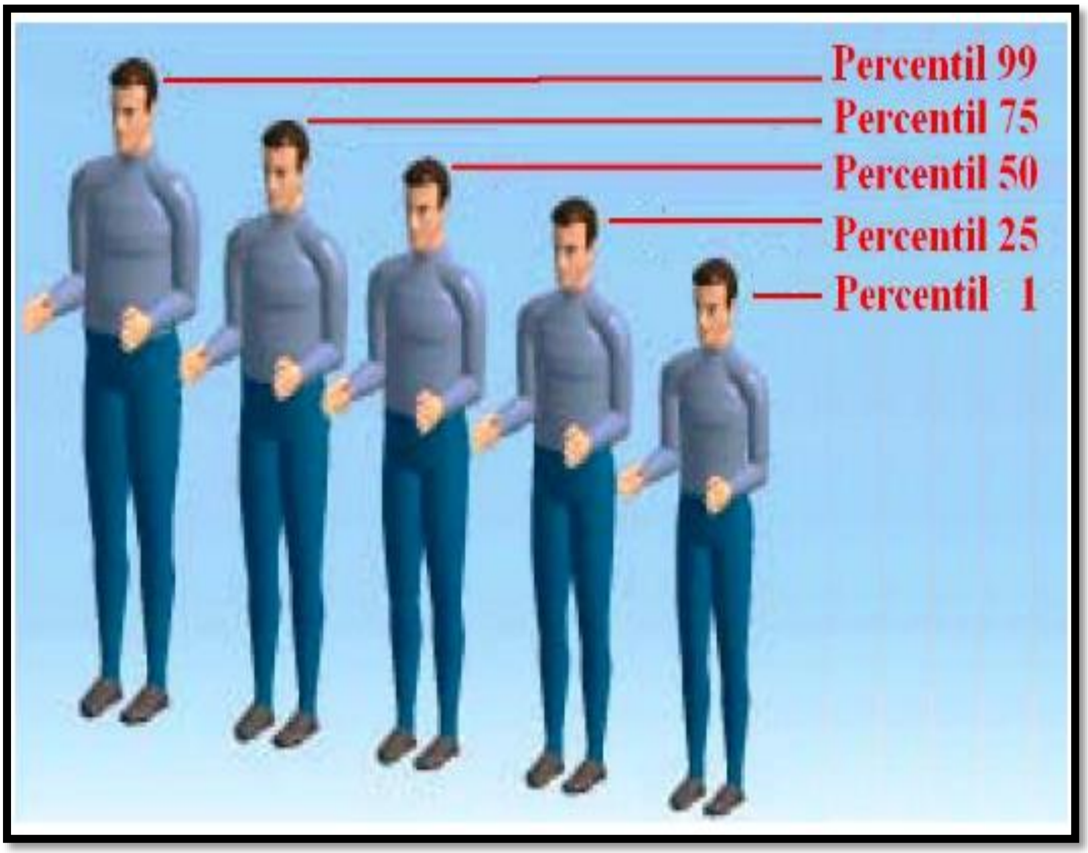


Figure 3.10: Percentiles illustration

Source: (Of, Process & data, 2019).

The calculations for the 5th, 50th, and 95th percentiles using the normal distribution are shown in the following formulas (3.4), (3.5), and (3.6) (Deros et al., 2009):

For 5th percentile $= u - 1.65\ \alpha$ ……………………………..…………………… (3.4).

For 50th percentile $= u + z\ \alpha$ …...………...………...………..…………………… (3.5).

For 95th percentile = $u + 1.65$ α …...…...…………………..…………………… (3.6).

Where α represents the standard deviation, μ denotes the mean, and z indicates the score. For better understanding, a basic normal distribution graph is illustrated in Figure 3.11, clearly depicting 90% of the distribution.

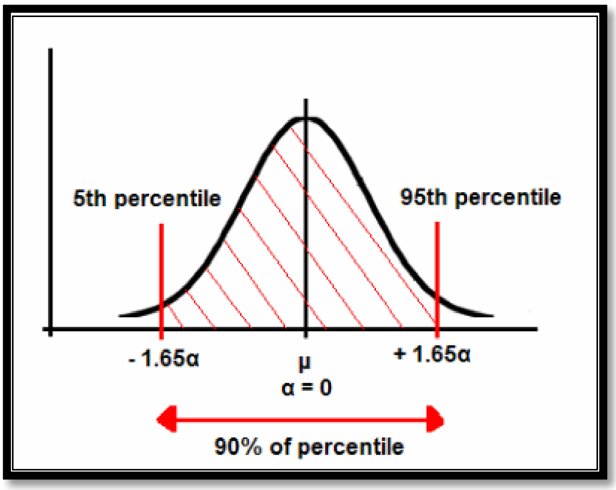


Figure 3.11: The normal distribution graph

Source: (Deros et al., 2009).

The process of calculating the percentile of a database set using Minitab is as follows (Borges, 1990):

1. Arrange the data so that the entries range from the smallest to the largest values (ascending order).
2. Calculate an index i (the position of p^{th} percentile) using the following formula (3.7) (Borges, 1990):

$i = \left(\frac{P}{100}\right) * $ n ……………………………..……..………..…………………… (3.7).

Where:

P is the percentile and n is a number of values present in the data. If i is not an integer, round it up, the next integer greater than i indicates the position of the p^{th} percentile. If i is an integer, the p^{th} percentile is the average of the values in positions i and i + 1.

To calculate the 5^{th}, 50^{th}, and 95^{th} percentiles of the collected data, as used in the following formula (3.8) (Of & Student, 2021):

$$Xp = \bar{x} + Zp * S \ldots\ldots (3.8).$$

Where,

X_p is the P^{th} percentile value of variable x.

Z_p is the standard normal values corresponding to the P^{th} percentile value x are: for the 5^{th} percentile, Z0.05 = -1.645; for the 50^{th} percentile, Z0.5 = 0; and for the 95^{th} percentile, Z0.95 = 1.645. These values can be found in the standard normal Table in the Appendix IX.

3.2.11.4 Characteristics of the Sewing Workstation in the Garment Manufacturing

The incorporation of anthropometric data in the ergonomic redesign of the sewing chair and the adjustable sewing machine table for the workers at REAL, Eldoret, Kenya was based on the following criteria:

1. Seat height: The popliteal height while sitting should be taken into account in the redesign of the seat height. Furthermore, the study by Ismaila et al., (2013), recommended using the 5^{th} percentile of popliteal height, plus an allowance of 0.45 cm for shoe heel. Additionally, the 5^{th} percentile of sitting popliteal height is 41.20 cm, and when this is combined with the shoe heel allowance of 0.45 cm, the seat height should be 41.65 cm.
2. Seat depth: The anthropometric dimension to consider in the redesign of the seat depth is the buttock popliteal length. Moreover, research by Mohamed et al., (2010) recommended using the 5^{th} percentile of the buttock popliteal length to determine the seat depth. In this research, the 5^{th} percentile of the buttock popliteal length is 46.20 cm, thus the seat depth is 46.20 cm.

3. Seat width: The hip breadth while sitting should be considered in the redesign of the seat width. Research by Musa & Ismaila, (2014) recommended using the 95th percentile of hip breadth sitting, plus a clothing allowance of 15 percent. In this research, the 95th percentile of hip breadth sitting is 41.55 cm, with an allowance of 15 percent (6.23 cm), resulting in a seat width of 47.78 cm.
4. Backrest width: According to Ismail Ismaila et al., (2013), the backrest width is the same with seat width of the redesign, which is 47.78 cm as determined above.
5. Backrest height (Upper) above seat: In redesigning the upper section of the backrest, the 5th percentile shoulder height while seated is taken into account, as noted by Mohamed et al. (2010). Furthermore, the 5th percentile shoulder height measured for this study is 49.50 cm.
6. Backrest height (Lower) above seat: The lower section of the backrest is determined by the height of the armrest. This value corresponds to the 5th percentile of sitting elbow height, which is 13.25 cm.
7. Armrest height: The sitting elbow height is a key factor in the proposed redesign of armrest height. Furthermore, previous research by Ismaila et al., (2013) indicated that while the lowest value is accommodated, others can also be accommodated; thus, the 5th percentile of elbow height was considered in the redesign, which is 13.25 cm.
8. Backrest angle: According to Ismaila et al., (2013), the backrest should have a rearward slope between 90° and 110°, while research by Mohamed et al., (2010), recommended 96°. Consequently, a rearward slope of 109° is adopted in this present research to ensure effective backward support.
9. Seat angle: As proposed by Igbokwe et al., (2019), the seat angle should be 110°.

10. Sewing table height: According to Ismaila et al., (2013), the maximum table height is calculated as seat height (41.65 cm) + functional elbow height + shoe heel allowance (0.45 cm). The functional elbow height was determined using the equation provided by Ismaila et al., (2013) as follows: 0.8517 * 5th percentile of elbow height sitting (13.25 cm) + 0.1483 * 5th percentile of shoulder height sitting (49.50 cm). Thus, the functional elbow height = (0.8517 * 13.25) + (0.1483 * 49.50) = 11.29 + 7.34 = 18.63 cm. Therefore, the maximum sewing table height for this study is 41.65 cm + 18.63 cm + 0.45 cm = 60.73 cm.
11. Sewing table depth: The distance between the elbow and the hand should be a key dimension when determining the table depth. According to Ismaila et al., (2013), the average redesign concept for the sewing table depth is based on the 50th percentile of forearm fingertip length, which is 45.72 cm.
12. Sewing table width: The study by Ismaila et al., (2013) recommended that the table width should be based on the 95th percentile of hip breadth of the user, with allowances for clothing and clearance. The 95th percentile of hip breadth (41.55 cm) plus 15 percent for clothing allowance (6.23 cm) and another 15 percent for clearance (6.23 cm) is adopted in this study. The sewing table width for this study is 41.55 cm + 6.23 cm + 6.23 cm = 54.01 cm.
13. Sewing table angle to horizontal: A study by Ahmed, (2018) proposed that the sewing table should be positioned at an angle of 15° towards the user to reduce the visual angle and promote an upright trunk posture. Research by Ismaila et al., (2013) suggested that the table should have an angle of inclination between 15° and 20°. Therefore, the sewing table angle for this study should tilt towards the user at an angle of 15°.

3.2.11.5 Data Collection for Existing Sewing Furniture Dimensions

In a REAL factory, the sewing furniture utilised by garment workers is not designed according to ergonomic principles. The dimensions of the sewing furniture are assessed to determine the compatibility or incompatibility between these dimensions and the workers' anthropometric data. Additionally, the following dimensions were collected directly using a measuring tape and goniometer. Table 3.9 presents the definitions of the existing sewing workstation furniture dimensions. Refer to Appendix X for the form detailing the sewing workstation furniture dimensions.

Table 3.9: Existing Sewing Furniture dimensions

No	Dimensions	Description	Reference
1	Seat height	Minimum distance measured vertically from the floor to the highest point on the front of the seat.	M. Ali, et al., (2014).
2	Seat depth	Minimum distance measured horizontally from the front edge of the sitting surface.	
3	Seat width	Horizontal distance between the larger edges of the seat.	
4	Sewing table height	Minimum distance measured vertically from the upper edge of sewing table to floor.	

3.2.11.6 Mismatch between Garments Furniture and Body Dimensions

The comparison of the anthropometric dimensions of workers with the corresponding dimensions of existing sewing furniture is crucial for designing ergonomic garment furniture. Therefore, the anthropometric data of the workers is compared to the relevant garment furniture dimensions. Furthermore, the researchers recommend measuring the popliteal height against the seat height, the buttock-popliteal length against the seat depth, the hip breadth against the seat width, and the sitting elbow height against the sewing table height to determine the garment furniture's compatibility using match criterion equations. The literature indicates that relationships have been identified to ascertain matches and mismatches. Additionally, mismatch equations have been established. Consequently, these equations are presented in the following sections (Ahmed, 2018):

3.2.11.6.1 Popliteal Height (PH) Against Seat Height (SH)

The Seat Height (SH) must be adjusted in relation to the Popliteal Height (PH). Researchers have indicated that the SH should be lower than the PH, allowing the lower leg to form angles between 50 and 300 degrees relative to the vertical (M. Ali, et al., 2014). Furthermore, an excessively low SH increases weight on the ischial tuberosities, while an excessively high SH raises pressure at the popliteal fold (the underside of the knee), which may impair blood circulation and elevate pressure on the nerve. The matching criterion for the SH is defined by the following equation (3.9) (Ahmed, 2018):

$(\mathrm{PH} + 3)\ \mathrm{COS}\ 30^0 \leq \mathrm{SH} \leq (\mathrm{PH} + 3)\ \mathrm{COS}\ 5^0$………………………...…..… (3.9).

3.2.11.6.2 Buttock Popliteal Length (BPL) Against Seat Depth (SD)

The Buttock Popliteal Length (BPL) is the anthropometric measurement used to determine the size of the Seat Depth (SD). If the SD exceeds the BPL, workers will struggle to use their backrests for lumbar spine support without compressing the popliteal surface. To counter this, workers typically shift their buttocks forward toward the seat's edge. This improper use of the backrest can lead to a kyphotic posture. Conversely, if the SD is significantly shorter than the BPL, workers' thighs will not receive adequate support. Therefore, most researchers recommend that the SD should be at the 5^{th} percentile of the BPL, ensuring that the seat's backrest can support the lumbar spine without compressing the popliteal surface (Gouvali & Boudolos, 2006). Additionally, the matching condition is established by the following equation (3.10) (M. Ali, et al., 2014):

$$0.80\ \text{BPL} \leq \text{SD} \leq 0.95\ \text{BPL} \quad (3.10).$$

3.2.11.6.3 Hip Breadth (HB) against Seat Width (SW)

The Hip Breadth (HB) is the anthropometric dimension that defines the Seat Width (SW). Furthermore, the SW should be sufficiently large to accommodate users with the largest HB (M. Ali, et al., 2014). Additionally, most researchers recommend that the SW be at the 95th percentile of the HB to ensure a proper fit in the seat. It should be at least 10% larger (to accommodate hip breadth) and at most 30% larger than the HB for space efficiency. Moreover, the matching criterion for the SW is established by the following equation (3.11) (Ahmed, 2018):

$$1.1\ \text{HB} \leq SW \leq 1.30\ \text{HB} \quad (3.11).$$

3.2.11.6.4 Elbow Height (EH) Against Table Height (TH)

The Elbow Height (EH) is regarded as a key factor in determining the sewing Table Height (TH). For example, if the TH is too low, workers will have to bend their torsos forward to see the point of operation, which can lead to kyphosis and a rounded shoulder posture. Conversely, if the TH is too high, workers will need to flex and abduct their upper arms while raising their shoulders. Additionally, the researchers found that the TH is influenced by the workers' shoulder flexion and abduction (Ankara, 2022, Castellucci et al., 2020, and Castellucci et al., 2015). The TH is defined by the following equation (3.12) (Dianat et al., 2013).

$$\text{PH} + \text{EH} \leq \text{TH} \leq \text{PH} + \text{EH} + 5 \quad (3.12).$$

3.3 Redesigning a Workstation for Garments-Making Workers at the Sewing Operations

3.3.1 Introduction

The third specific objective of this research is to redesign a workstation for garment-making workers at the sewing operation. Utilising the collected anthropometric data, an ergonomic sewing workstation for garment workers was proposed. SolidWorks was employed to develop eight different conceptual redesigns of the ergonomic sewing chair workstation, from which one option was selected using the Concept Scoring Method (CSM). To determine the best option, relevant data was gathered from the workers through a survey. To achieve the third specific objective, the entire methodology can be divided into the following steps, as illustrated in Figure 3.12.

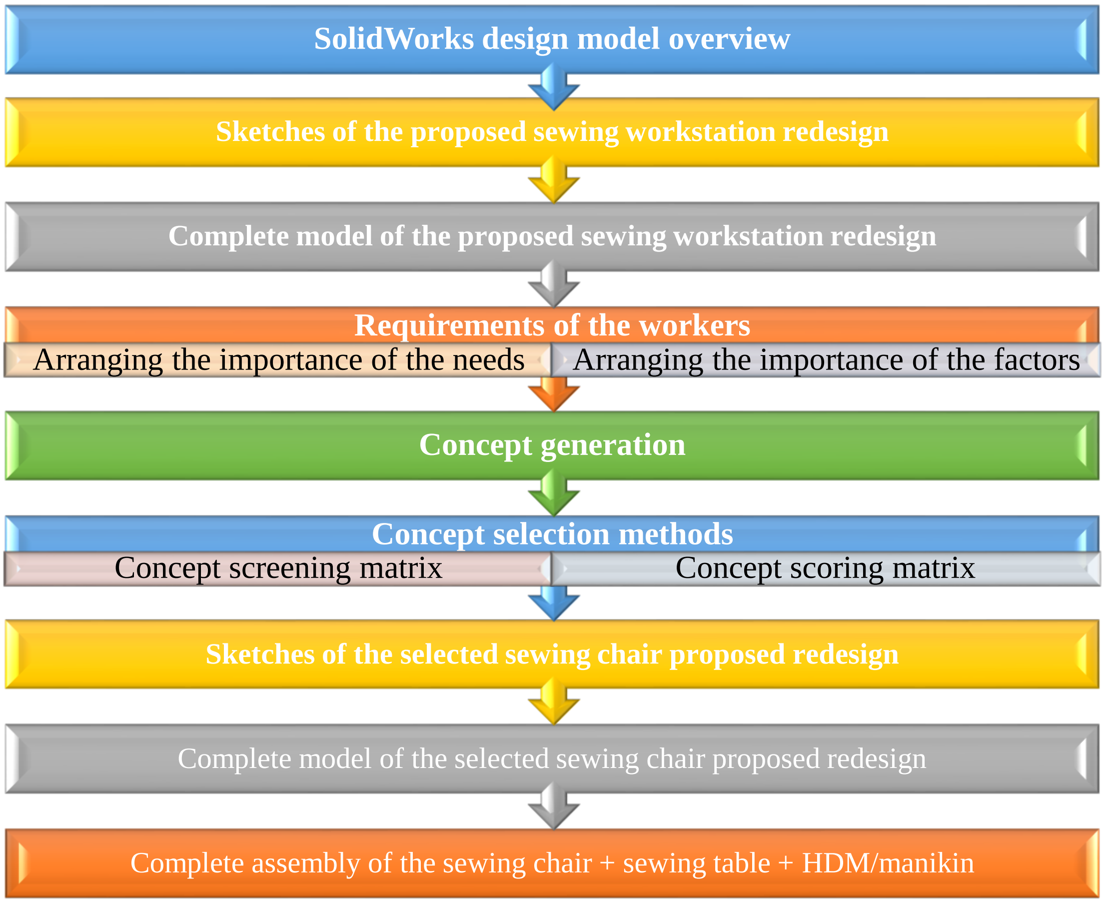


Figure 3.12: Main steps of the sewing workstation redesign methods

3.3.2 SolidWorks Design Model Overview

Nowadays, the SolidWorks software environment is an outstanding and powerful 3D design tool that assists designers and engineers in designing, simulating, and optimising the workstation (Paper et al., 2013). According to previous studies by many researchers, including Planchard, (2018), Planchard & Planchard, (2006), SolidWorks, (1995), (2010), and Systèmes, (2020), SolidWorks is recognised as an industrial design automation tool. It allows users to quickly understand and design, sketch out ideas, and incorporate features and dimensions to produce effective models and detailed drawings. The SolidWorks model consists of 3D geometry that encompasses all edges, faces, and surfaces. Additionally, SolidWorks enables the rapid and precise creation of any design model. A 3D geometry serves as a model sketch that designers and engineers aim to develop and generate various manufacturing products. SolidWorks is an exceptional 3D engineering and design tool, providing engineers and designers the capability to visualise ideas, experiment with features and dimensions, and produce models and detailed drawings. Furthermore, the 3D design approach in SolidWorks begins with an initial sketch on paper, which is then transferred to SolidWorks to construct the parts from the initial sketch. Subsequently, these parts are combined into one assembly to achieve the final design. Additionally, SolidWorks primarily utilises three programs, as outlined in Table 3.10, and Figure 3.13 illustrates the systematic steps involved in designing with SolidWorks.

Table 3.10: Model of SolidWorks software

S. no.	Programmed	Programmed discussion	Reference
1.	Part	This model is used for design methods, tools, and features mainly used to make parts.	SolidWorks, (1995)
2.	Assembly	In this model the designer assemble all the parts which are developed in the part model section. This section, identifies interference, specify mate, and is used for context design purpose.	
3.	Drawing	This is basically a discussion of a drawing sheet format, dimension views, full annotation, and also the Bill of Material (BOM).	

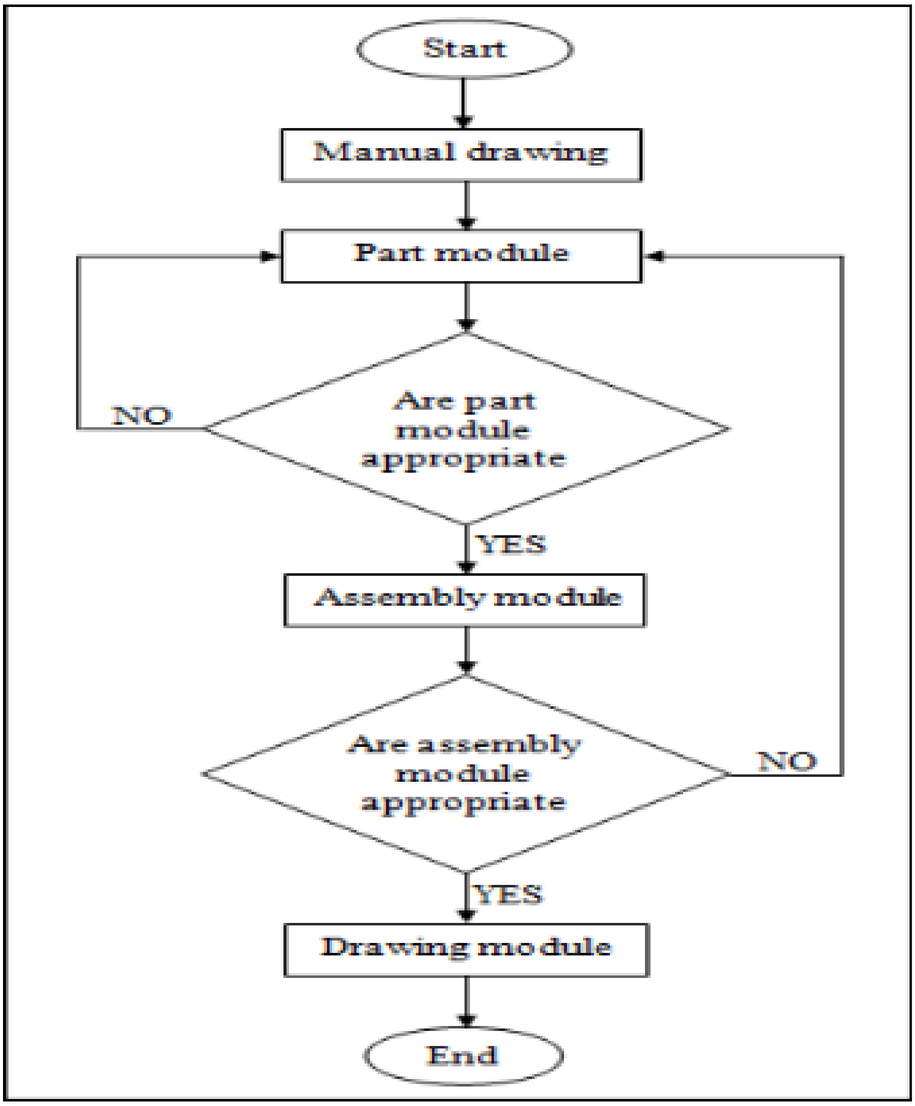


Figure 3.13: Systematic steps in redesigning using SolidWorks software

3.3.3 Requirements of the Workers

A current study targeting key stakeholders at REAL, Eldoret, Kenya was conducted. Additionally, 100 respondents (50% male and 50% female) were randomly selected from garment workers at the sewing workstation. A survey was chosen as the most common and suitable method, which was pre-tested to ensure its validity and reliability. Furthermore, the questionnaire data was analysed list-wise in Minitab 17.0 software based on the following sections:

3.3.3.1 Arranging the Importance of Needs

The eight conceptual sewing chair redesigns were organised according to the importance of the needs, which are: A. Adjustable height and back sewing chair, B. Adjustable height sewing chair, C. Arrow and craft sewing chair, D. Camping sewing chair, E. Arm sewing chair, F. Armless sewing chair, G. Sindre sewing chair, and H. Folding sewing chair. This ranking was conducted on a scale from 1 to 5 (1 being the lowest and 5 the highest).

3.3.3.2 Arranging the Importance of Factors

The important factors that can be arranged for workers' requirements include: aesthetics, ergonomics, safety, durability, ease of use, reliability, ease of manufacture, usability, social appeal, maintainability, life cycle cost, environmental soundness, economic value, utility, and function.

3.3.4 Concept Generation

The idea for redesigning the current sewing chair workstation emerged from a thorough analysis of the workers' requirements. At this stage, eight distinct concepts for the sewing chair workstation redesign were developed based on the needs of the workers.

3.3.5 Concept Selection Methods

The concept selection method involves evaluating concepts based on workers' needs and other criteria, comparing their relative strengths and weaknesses, and selecting one or more concepts for further investigation and development. Furthermore, concept selection encompasses both concept screening and concept scoring processes, each supported by a matrix as discussed below (Nanyang Technology University, 2014):

3.3.5.1 Concept Screening Matrix

The concept screening matrix is a method used to quickly narrow down the number of concepts and enhance their quality. Furthermore, the concept screening matrix is regarded as a means to reduce the number of selected concepts and ultimately choose one final concept.

3.3.5.2 Concept Scoring Matrix

After generating all eight sewing chairs, redesign the workstation concepts. The next step was to select the best sewing chair to redesign the workstation for simulation, optimisation, and fabrication. Furthermore, both the concept screening matrix and concept scoring matrix processes are guided by a six-step procedure, which leads the sewing chair redesign team through the concept selection matrix activity. These six steps are (Pdd, 2014):

1. Preparing the selection matrix according to the worker's requirements: Additionally, employing hierarchical relations effectively clarifies the criteria.
2. Evaluating the proposed redesigns of the sewing workstations based on the worker's requirements: A suggested scale ranges from 1 to 5 (1 being the lowest and 5 the highest) according to the workers' requirements, which are defined and categorised in Table 3.11.

Table 3.11: Relative performance and their rating

Relative performance	Rating	Reference
Much worse than the reference	1	Nanyang Technology University, (2014).
Worse than the reference	2	
Same as the reference	3	
Better than the reference	4	
Much better than the reference	5	

3. Ranking the concepts of the proposed redesigns for the sewing workstations based on the workers' requirements. After entering the ratings for each concept, the weighted scores were calculated by multiplying the raw scores by the criteria weights. Once all concepts were rated, a total score for each design was computed using the following formula (3.14) (Xiao et al., 2011, and Nanyang Technology University, 2014):

Total score = $\sum_{1}^{n} w_n * d_n$ …………………………………..………………… (3.14).

Where:

n is the number of selection criteria,

w_n is the weight of n_{th} criteria, and,

d_n is the rating of the n_{th} criteria.

4. Integrating and enhance the concepts of the sewing workstations with suggested redesigns tailored to the worker's needs.
5. Choosing one or more concepts for the sewing workstation redesigns based on the worker's needs.
6. Evaluating the outcomes and the process of the proposed redesigns for the sewing workstations according to the worker's requirements.

the overall performance of the proposed ergonomic sewing concept redesigns is ranked according to their total score.

3.3.6 Sketches of the Selected Concept Sewing Workstations Proposed Redesign

The sketches of the proposed redesigns for the concept sewing workstation were developed after analysing all the workers' anthropometric measurements, which were conducted using ISO 7250-1:2017 as a technical standard procedure. Furthermore, the inspiration for the sketch derives from the automotive redesign for the sewing workstation, where workers are required to be seated, and this sketch of the sewing workstation was elaborated in detail. In this research, SolidWorks was utilised for accurate and appropriate drawing processes.

3.3.7 Complete Model of the Selected Concept Sewing Workstations Proposed Redesign

The final modeling processes of the sewing workstation were completed using SolidWorks 2024 software, incorporating the rendering processes for the ergonomic redesign based on the workers' anthropometric data at REAL, Eldoret, Kenya.

3.3.8 Complete Assembly of the Sewing Workstation Redesign

After modeling in SolidWorks, the models were imported into CATIA V5 software to complete the assembly of the selected sewing chair, adjustable sewing machine table, and HDM for the simulation test.

3.4 Simulating the Redesign of Workstations for Garments-Making Workers at the Sewing Operation

3.4.1 Introduction

The fourth specific objective of the present research is to simulate the redesign of workstations for garment-making workers at the sewing operation. Using the collected anthropometric data, an ergonomic sewing workstation for garment workers was modeled and proposed. Additionally, the Rapid Upper Limb Assessment (RULA) analysis and Finite Element Analysis (FEA) were conducted on the models of the Human Digital Model (HDM) and the sewing chair workstation to create an ergonomically suitable workstation for the users. Furthermore, the RULA ergonomic analysis method was applied to assess the sitting posture of the ergonomic HDM for comfort. The FEA method was also utilised on the proposed model of the selected sewing chair to evaluate its capacity to support the weight of the human body. To achieve the fourth specific objective, the entire methodology can be divided into the following sections:

3.4.2 Simulation Methods of the Rapid Upper Limb Assessment (RULA) Ergonomic Analysis

The Rapid Upper Limb Assessment (RULA) is an ergonomic analytical tool that evaluates the biomechanical and postural load requirements of job demands on the neck, trunk, and upper extremities (Manzoor et al., 2019). Furthermore, ergonomic principles can be understood as the science of enhancing efficiency to meet user needs while minimising discomfort during use. Additionally, ergonomics aims to achieve the best possible alignment between the product and its user in the context of intended applications. The main steps for simulating an HDM on a seated body posture using CATIA V5, based on RULA analysis, are illustrated in Figure 3.14.

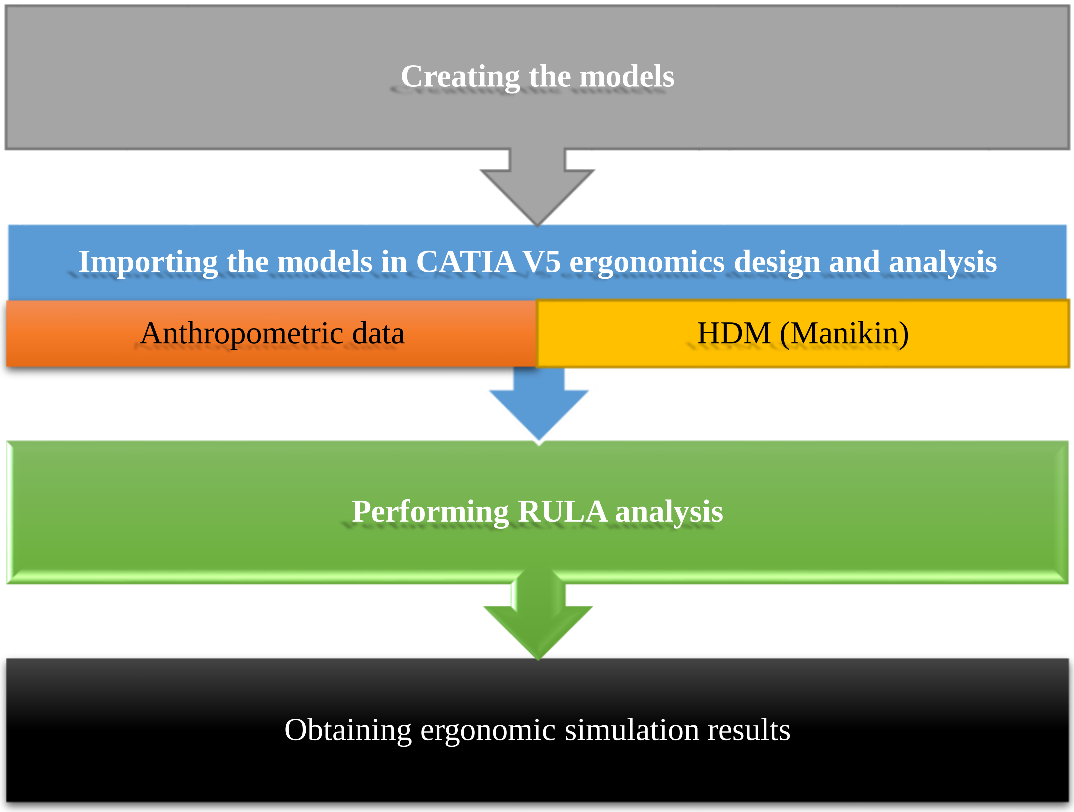


Figure 3.14: Main steps of the simulation of human modeling using RULA analysis

3.4.2.1 Creating Models in SolidWorks Software

The 3D models of the sewing workstation were developed in SolidWorks to simulate the sitting body posture of the HDM.

3.4.2.2 Importing the Models in CATIA V5 for Ergonomics Design and Analysis

After modeling in the SolidWorks simulation software, the sewing workstation models were imported into CATIA V5 to conduct the RULA ergonomic simulation and obtain results. Furthermore, the comfort of the sewing workstation relies on aesthetics, maintainability, material quality, ergonomics and safety, structure, ease of manufacture, shape, utility and function, handling, durability, and stability. Additionally, the structure and shape in the redesign of a sewing workstation depend on the available anthropometric data of the users. Figure 3.15 illustrates the method adopted for the redesign of a sewing workstation by HDM using CATIA V5 ergonomics design and analysis software based on the RULA analysis, as suggested by Paul et al., (2019), and Ye et al., (2013), and defined by four sub-models which are:

1. Human Measurement Editor Model (HMEM).
2. Human Activity Analysis Model (HAAM).
3. Human Builder Model (HBM).
4. Human Posture Analysis Model (HPAM).

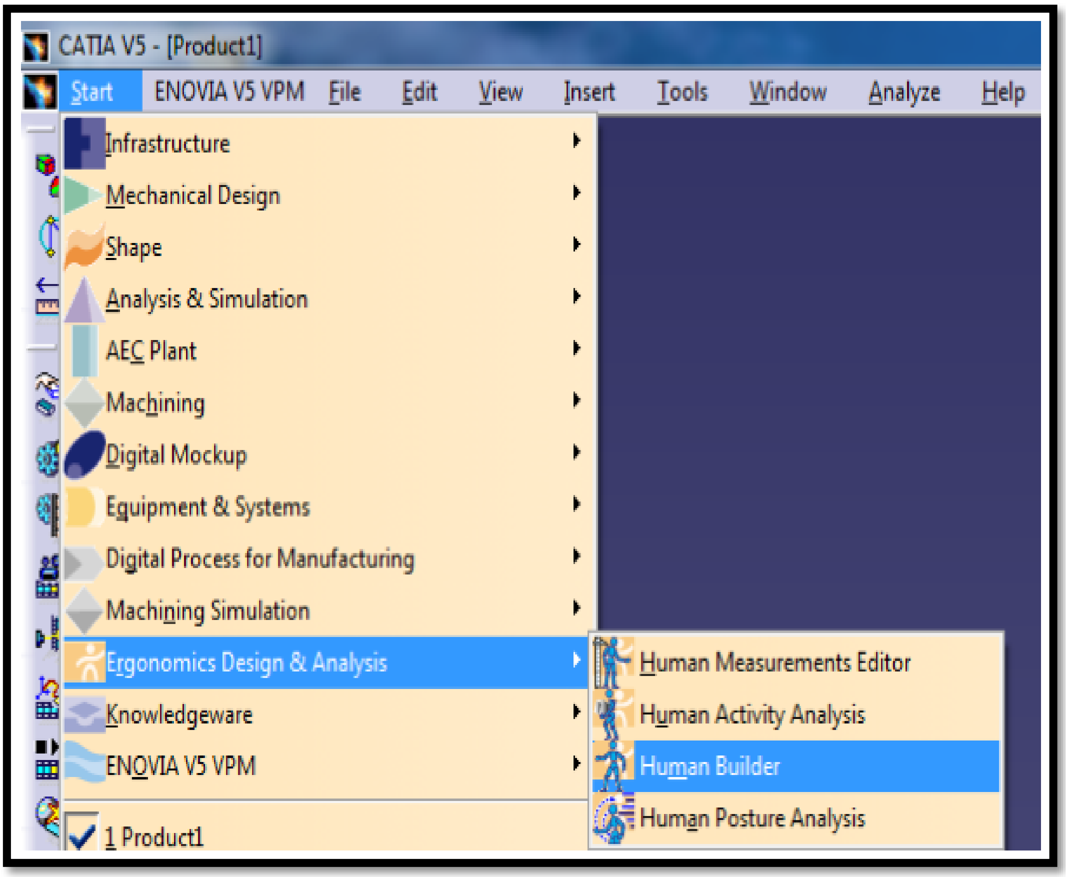


Figure 3.15: Ergonomics model in CATIA V5

3.4.2.2.1 Anthropometric Data for Manikin

Table 3.12 presents the essential 50th percentile of the sewing workers' anthropometric data inputs utilised in the development of the DHM in CATIA V5 ergonomics design and analysis software based on RULA analysis.

Table 3.12: 50^{th} percentile of the workers' anthropometric data for HDM

Variables (Sitting)	50^{th} percentile	Units	Input method
Sitting height	800.5	mm	Manual
Eye height, sitting	685.5	mm	Manual
Hip breadth, sitting	355.4	mm	Manual

3.4.2.2.2 Human Digital Model (HDM)

The focus of the Human Measurement Editor Model (HMEM) is to create an anthropomorphically detailed digital human for advanced ergonomic design and analysis, as well as accommodating a global target audience. Furthermore, the HMEM provides anthropometric data from five default populations: Japanese, American, French, Canadian, and Korean. Additionally, the digital human can be displayed in various body postures, such as sitting and standing, from different viewpoints, along with the related anthropometric variables (John et al., 2020, Paul et al., 2019, and Romli & Aminian, 2018). For this ergonomic design analysis, the digital human has been generated for the 50^{th} percentile of workers' anthropometric data. This setup is chosen to redesign a sewing workstation for the average user, which fits all. To conduct the analysis, the HDM must be integrated into section HAAM. This research was applied to a HDM using the HMEM. Furthermore, the specific postural analysis in CATIA V5 was based on the ergonomic body posture analysis of the RULA. Additionally, there are two steps that must be addressed before the final evaluation can be made: (1) to develop a HDM and (2) to assess the recommended redesign of the sewing workstation through ergonomic body posture and design analysis.

3.4.2.2.2.1 Development of a Human Digital Model (HDM)

A Human Digital Model (HDM) was created using the Human Builder Model (HBM) in CATIA V5. The tools in the HBM included HDM generation, gender specification, and percentile specification, as illustrated in Figure 3.16. Figure 3.17 displays the HDM in a sitting posture, based on the worker's anthropometric data. Furthermore, Figure 3.17 (a) presents the HDM generated, while a body posture editor is depicted in Figure 3.17 (b). Additionally, Figure 3.17 (c) demonstrates how dimensions were assigned to the HDM/manikin's variables.

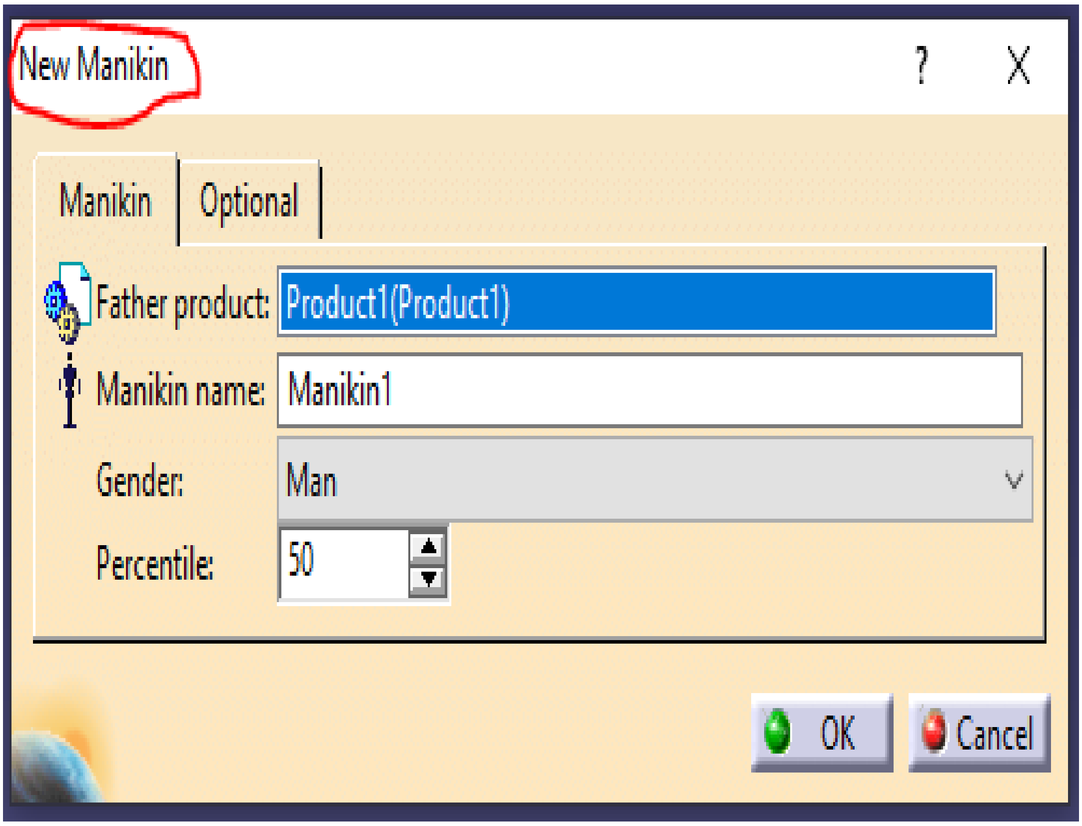
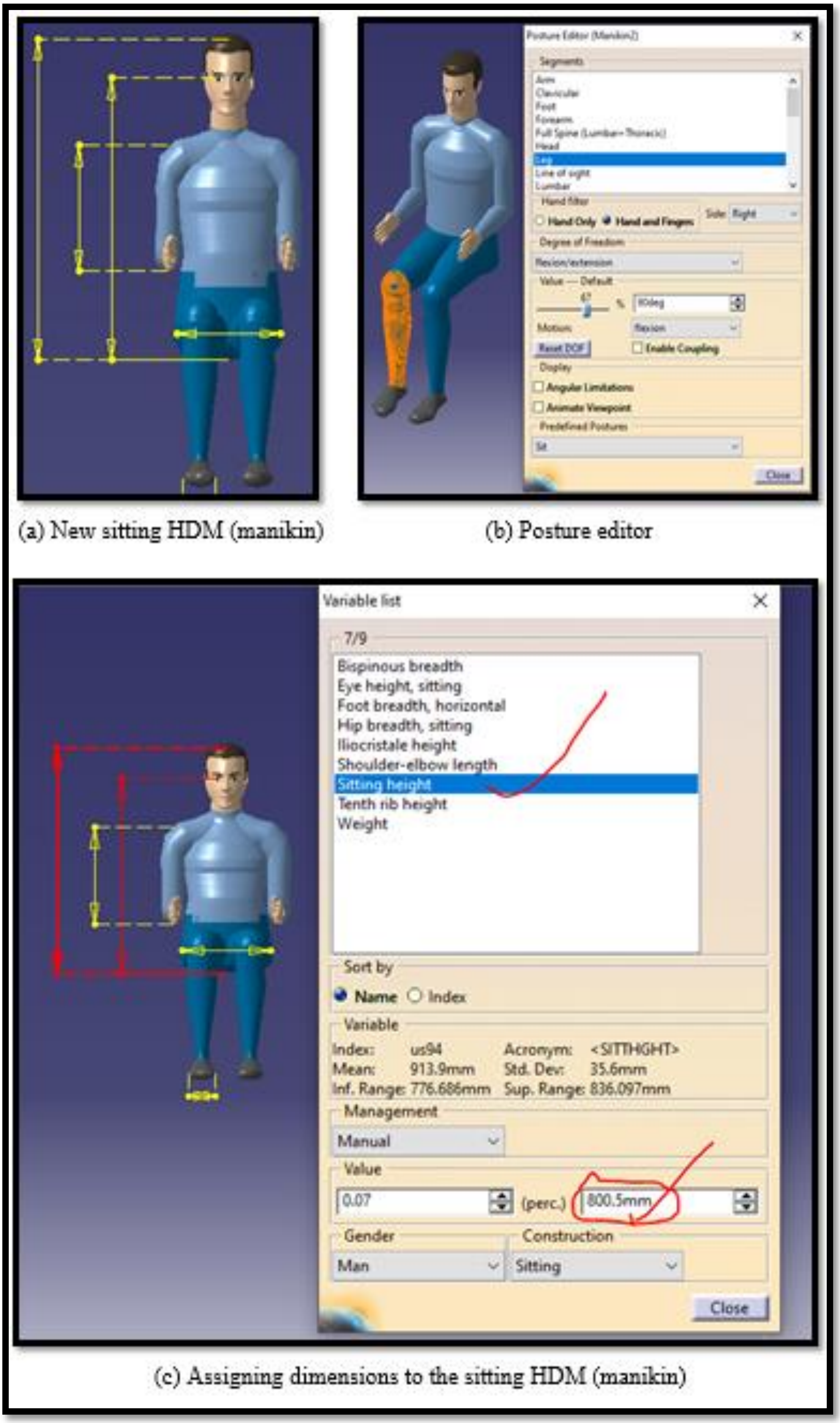


Figure 3.16: HDM (Manikin) insertion for this study



(a) New sitting HDM (manikin) (b) Posture editor

(c) Assigning dimensions to the sitting HDM (manikin)

Figure 3.17: HDM in the sitting posture using workers' anthropometric data

3.4.2.2.2.2 Assessment of the Recommended Sewing Workstation

The measurements of the sewing workers were integrated to develop the assembly of the sewing workstation, which includes a selected sewing chair, an adjustable sewing machine table, and an HDM setup, to enhance the work environment for garment manufacturing workers.

3.4.2.3 Performing RULA Analysis

The RULA analysis refers to a rapid upper limb assessment that evaluates the ergonomic risks associated with the upper limb extremities. This method is used to analyse disorders of the upper limb in various working environments and conditions. Furthermore, the primary aim of the RULA analysis is to assess the postural load requirements for human body parts. The RULA analysis generates a scorecard ranging from 1 to 7, accompanied by a colour code from green to red. If the score is 1 or 2, the work posture is deemed acceptable; otherwise, further investigation of body posture is necessary. To conduct a RULA ergonomic analysis, the following section can be discussed:

3.4.2.3.1 RULA Method and RULA Score

The RULA analysis tool is launched to select HDM (manikin). Additionally, Figure 3.18 displays the RULA dialog box in CATIA V5 for the final score and the actions required for this study. The side of the HDM for analysis and the predetermined best-suited body posture were selected. There are three types of posture: static, intermittent, and repeated. The intermittent posture involves repeating tasks four times or fewer within one minute, while the static and repeated options entail repeating the task more than four times in one minute. In the same body posture option within the parameters, the load is specified to indicate the weight of the object manipulated by the person. The

RULA analysis method is based on scores and colours, which are interrelated. The colours are green, yellow, orange, and red; green indicates that the body posture is good and acceptable, while red signifies that the body posture is poor and needs immediate adjustment. The scores are divided into four scales, each with its own description Romli & Aminian, (2018). See Table 3.13 for the RULA analysis score descriptions.

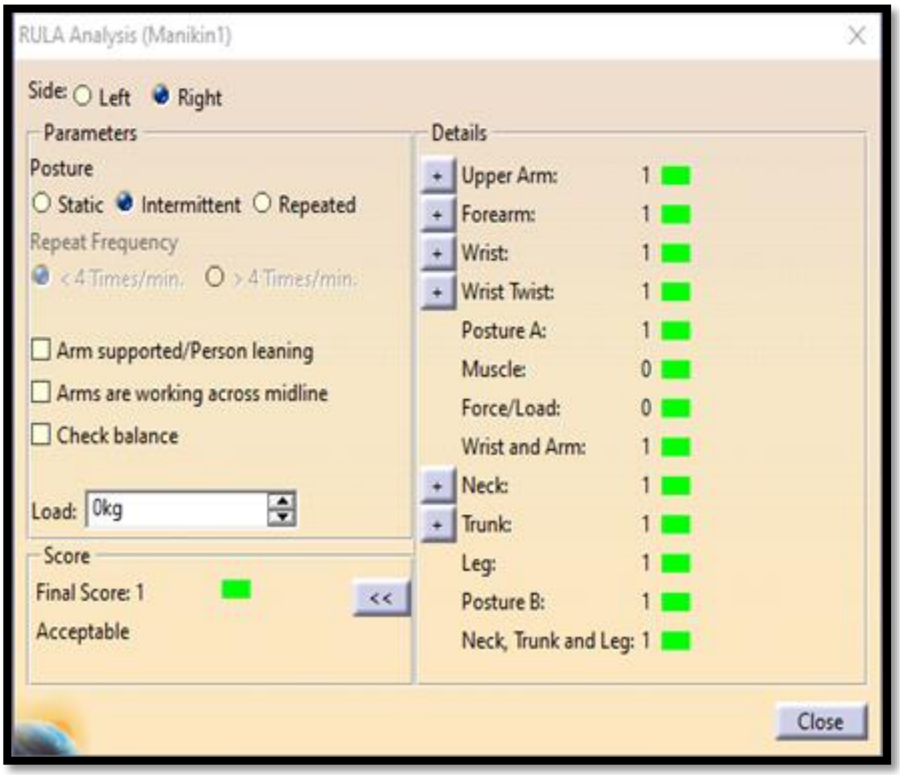


Figure 3.18: The RULA dialog box in CATIA V5

Table 3.13: RULA analysis score description

RULA Score	Risk Level	Action
1 - 2	Negligible	Acceptable
3 - 4	Low	Further investigation and changes may be needed
5 - 6	Medium	Investigation and changes required soon
7	High	Investigation and changes required immediately

3.4.2.4 Obtaining Ergonomic Simulation Results

The ergonomic simulation results for the RULA analysis were obtained, and the redesign of the sewing workstation based on anthropometric data was finalised.

3.4.3 Simulation Methods for Finite Element Analysis (FEA) Static Analysis

The Finite Element Analysis (FEA) is a crucial computerised numerical method that offers approximate solutions for structural and thermal analysis across various application areas. Additionally, to conduct the FEA static simulation and obtain results, the following steps can be utilised, as illustrated in Figure 3.19 (Esmaeel et al., 2024).

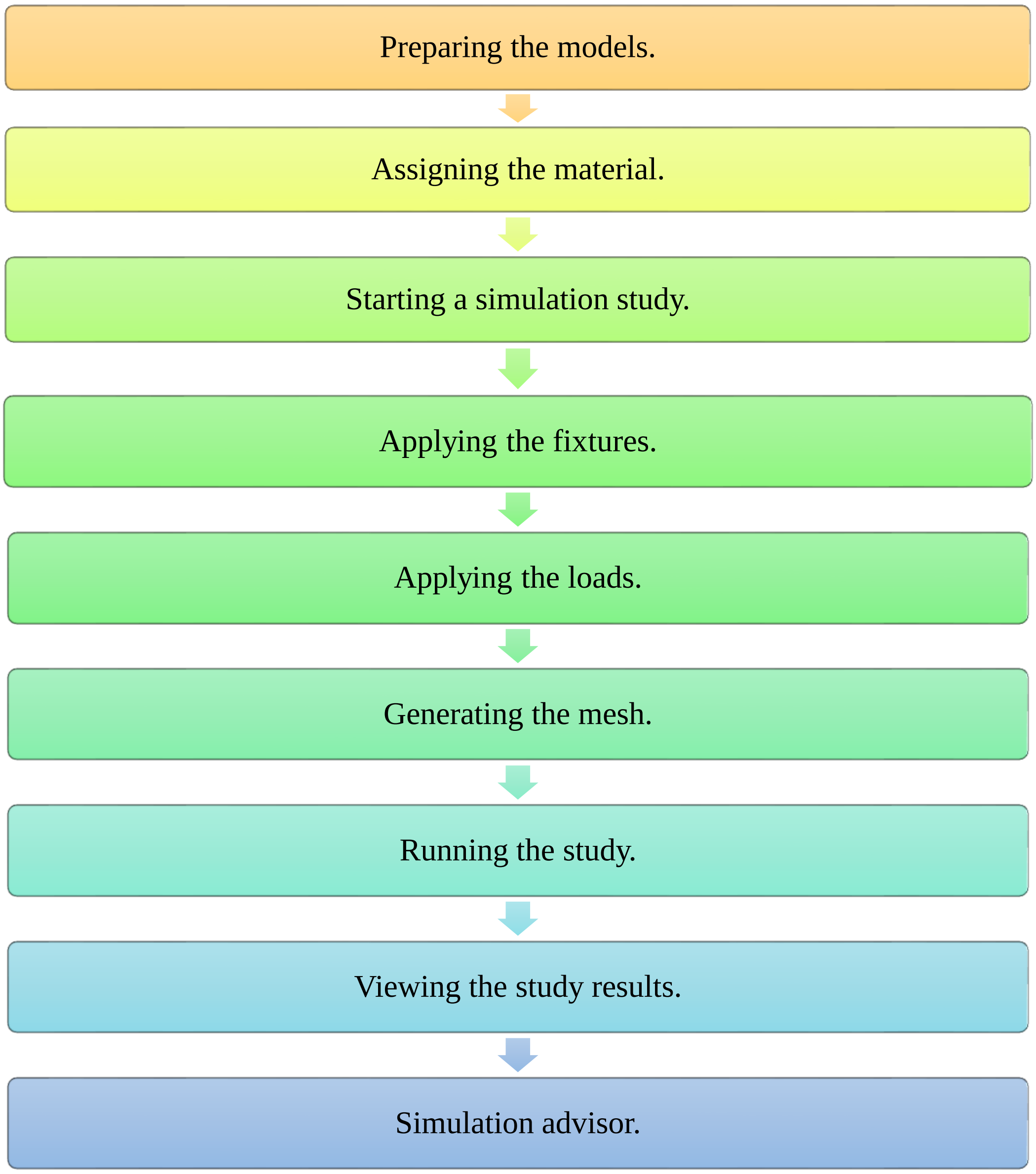


Figure 3.19: Main steps of the simulation models using FEA static analysis

3.4.3.1 Preparing the Model Using SolidWorks

The model of the chosen sewing chair was designed and constructed using part design in SolidWorks, a 3D finite element program based on the worker's anthropometric data. This model was utilised for FEA as the experimental simulation.

3.4.3.2 Assigning the Material

The response of a part model is determined by the material assigned to it. In the material dialog box, the material is selected and applied, as illustrated in Figures 3.20.

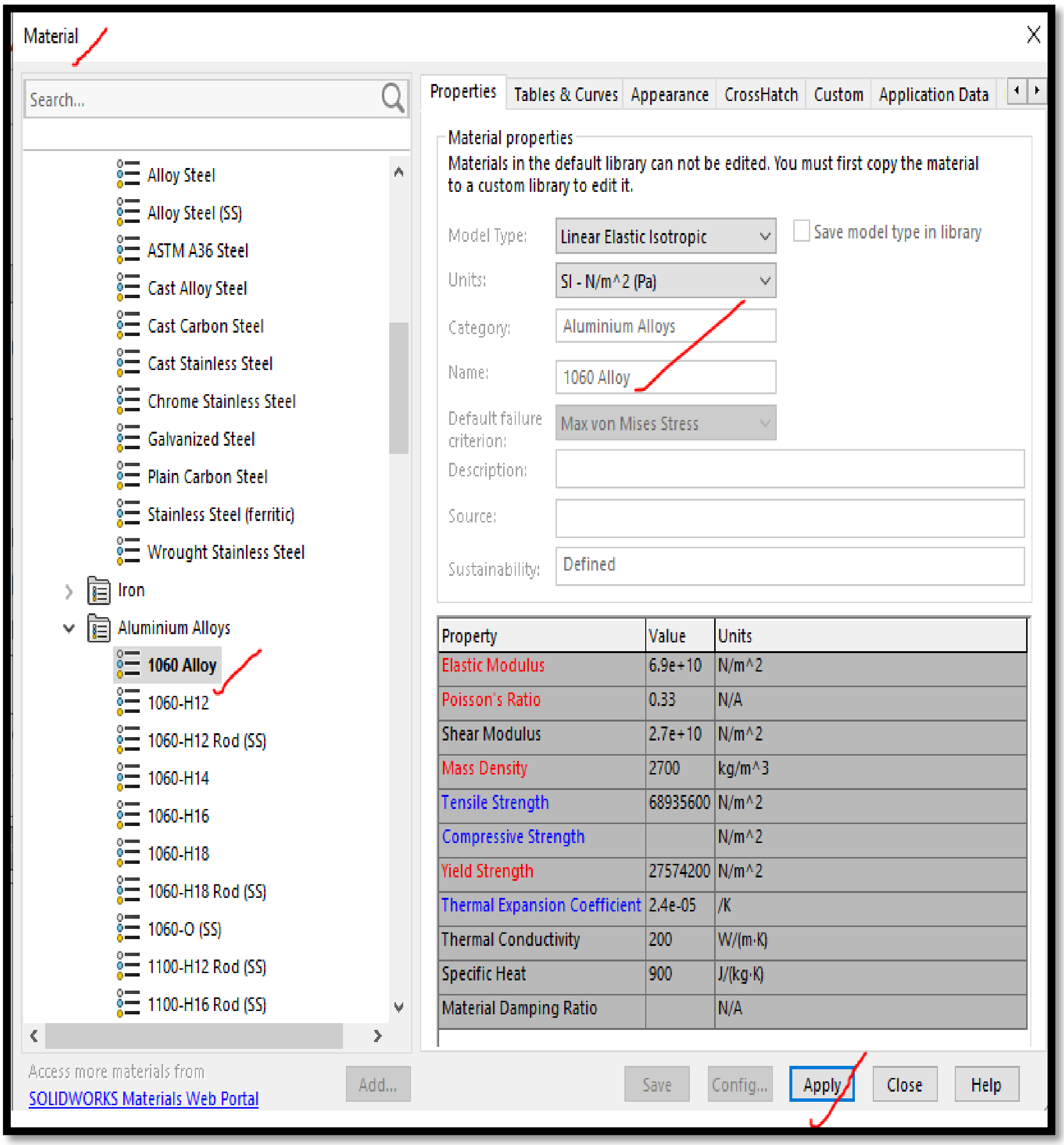


Figure 3.20: Assigning materials for the part model

3.4.3.2.1 Material Selection for Finite Element Analysis (FEA) Test

The properties considered in the materials selection were limited to (Madara et al., 2016; Miller, 1989): Technical properties of the materials such as density, conductivity, and strength; manufacturing aspects such as ease of production with existing facilities; economic factors like material cost and availability; and ecological properties including recyclability and sustainability. The aluminum alloy 1060 was chosen for the FEA test because it is the most widely used metal in furniture manufacturing due to its competitive cost, lightweight nature, corrosion resistance, simplicity in production, and excellent working properties, particularly for molded metal chairs. Furthermore, metals remain the preferred choice for furniture making due to their contemporary appearance, charm, and character. Additionally, the FEA static analysis was conducted on the selected sewing chair model to assess its ability to support the weight of the human body. Table 3.14 presents the specifications of the materials used.

Table 3.14: Specification of used material properties

Properties/Materials	Aluminium alloy 1060		References
	Value	Units	
Elastic modulus	69000	MPa	Kureshi et al., (2014), and Paper et al., (2013).
Poisson's ration	0.33	N/A	
Shear modulus	27000	MPa	
Mass density	2700	Kg/ m^3	
Tensile strength	6.893E + 01	MPa	
Yield strength	2.757E + 01	MPa	
Thermal conductivity	200	W/(m.k)	
Specific heat	900	J/(kg.k)	

3.4.3.3 Starting a Simulation Study

The simulation study for this research begins with the use of SolidWorks software to conduct the FEA static analysis on the selected sewing chair model, as illustrated in Figure 3.21.

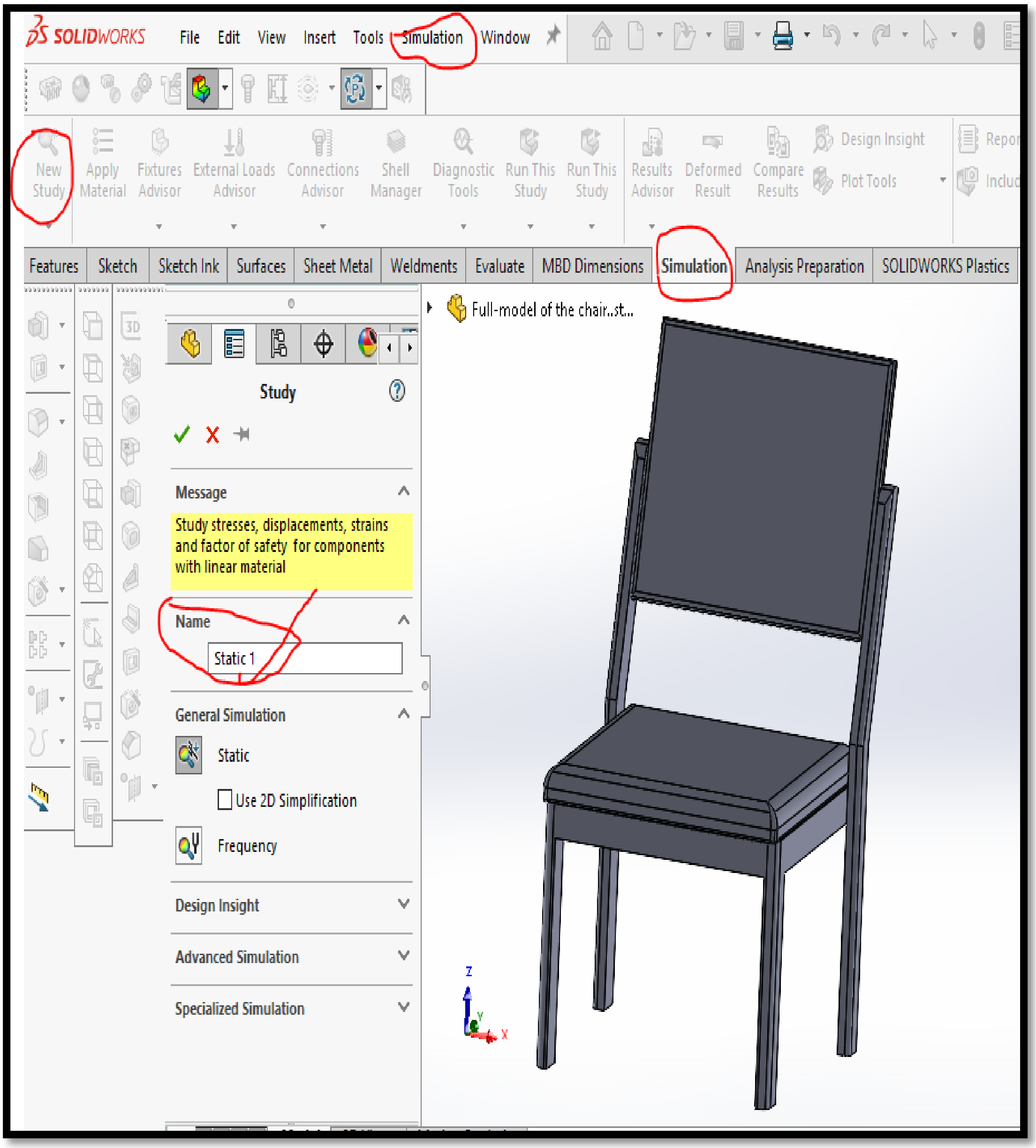


Figure 3.21: Starting a simulation study for the model

3.4.3.4 Applying the Fixtures

For the simulation analysis, the initial steps involve applying fixtures to the faces or edges of the model part. In this study, the fixtures were applied to the five faces of the selected sewing chair model, as illustrated in Figure 3.22 and detailed in Table 3.15.

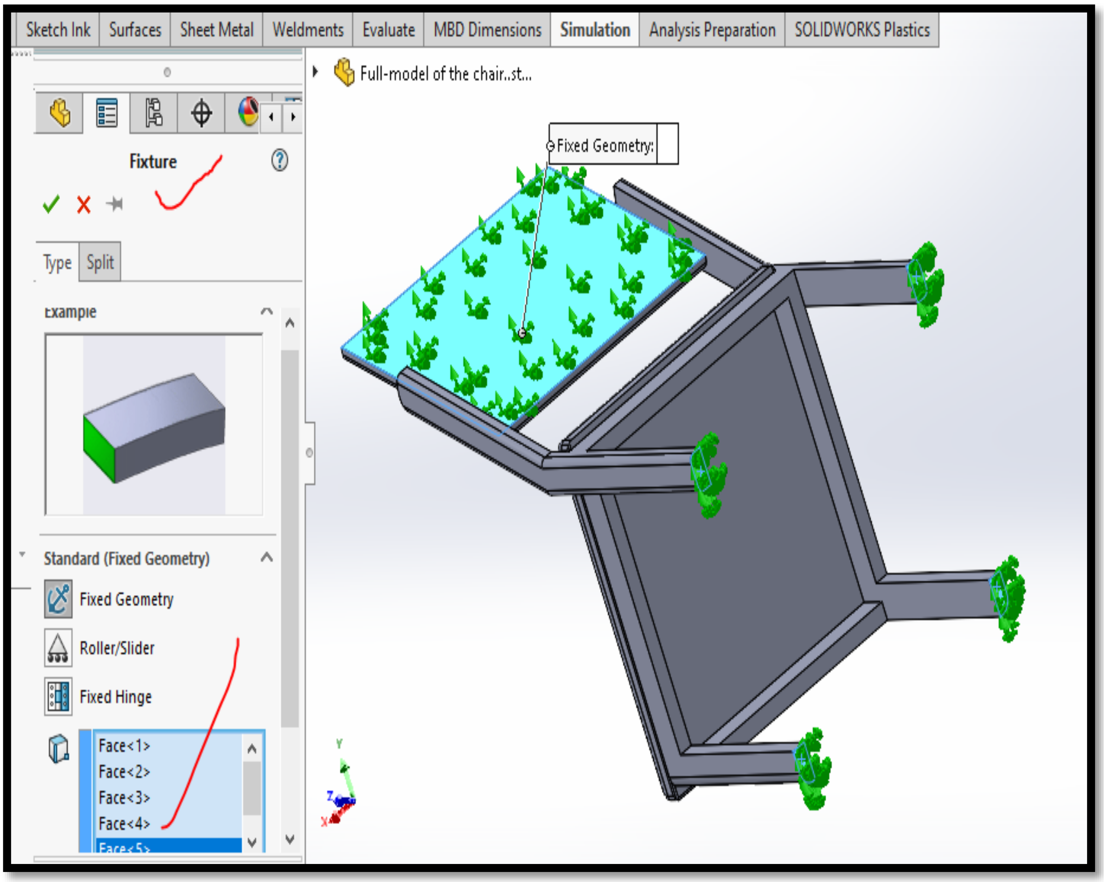
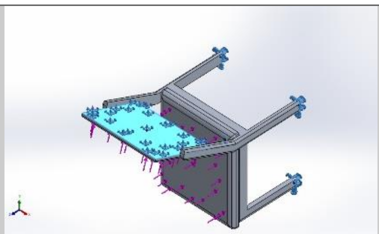


Figure 3.22: Applying fixtures in the five faces of the selected sewing chair model

Table 3.15: Applying fixtures in the selected sewing chair model

Fixture name	**Fixture Image**	**Fixture Details**	
Fixed-1		**Entities:**	5 face(s)
		Type:	Fixed Geometry

3.4.3.5 Applying the Loads

In the SolidWorks simulation, the loads on a redesigned part can consist of applied forces, pressure, or both, acting on the face and edges of the model. According to Mahantesh et al., (2023), an average human weight of 800 N (80 kg) was applied at the base seat of the selected sewing chair model, while an average human weight of 150 N (15 kg) was applied at the backrest of the same model, as illustrated in Figure 3.23 and detailed in Tables 3.16 and 3.17.

Table 3.16: Loads acting on the selected sewing chair

SI. No	Parts	Load (N)	Reference
1	Base seat of the selected sewing chair model	800	Mahantesh et al., (2023).
2	Backrest seat of the sewing chair model	150	

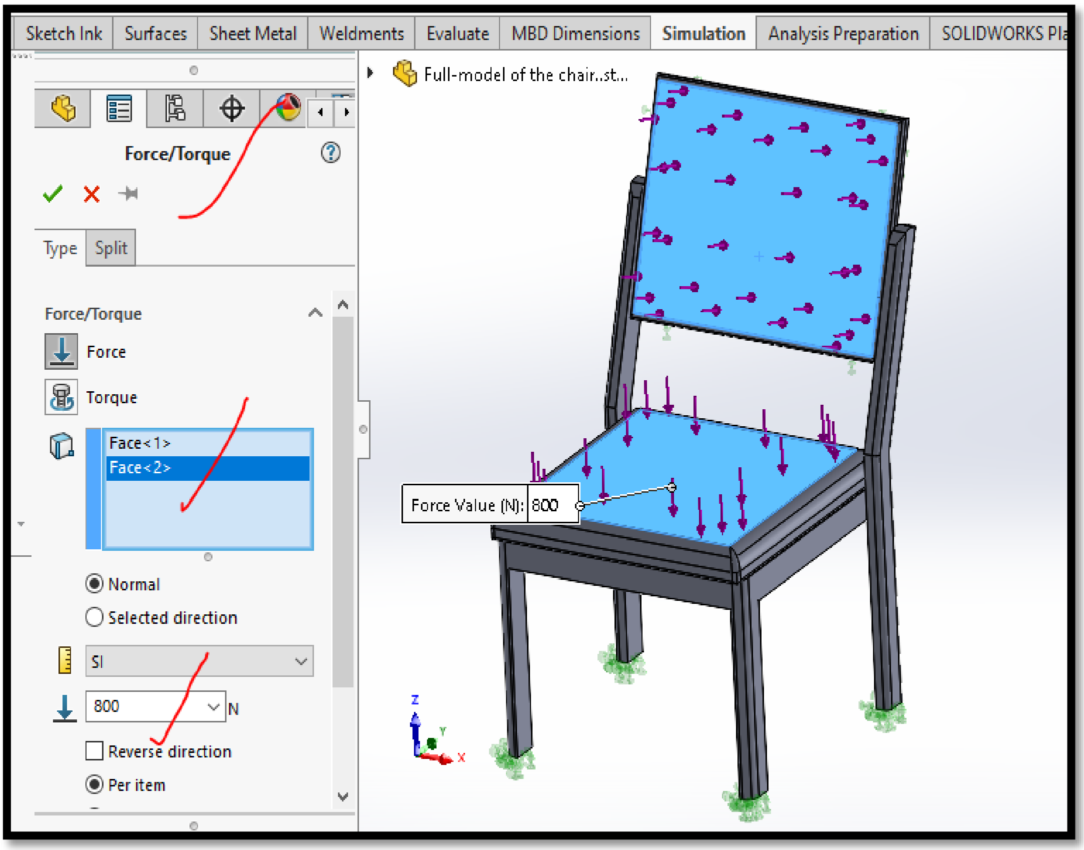
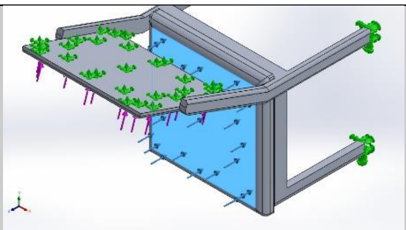
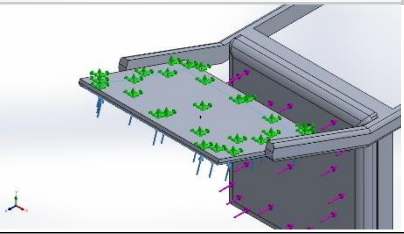


Figure 3.23: Applying the loads in the selected sewing chair model

Table 3.17: Applying the loads in the selected sewing chair model

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 800 N
Force-2		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 150 N

3.4.3.6 Generate the Mesh

The mesh was generated and analysed as shown in Figure 3.24 and Table 3.18. The element shapes used were tetrahedral and quadrilateral, with fine sizing. The generated mesh data included: maximum element size of 54.0261 mm; minimum element size of 2.70131 mm; high mesh quality; total nodes of 69,620; total elements of 39,657; maximum aspect ratio of 34.349; percentage of elements with aspect ratio < 3 at 98.8%; percentage of elements with aspect ratio > 10 at 0.00504%; percentage of distorted elements at 0; and the time to complete the mesh was 00:00:13 hh:mm:ss.

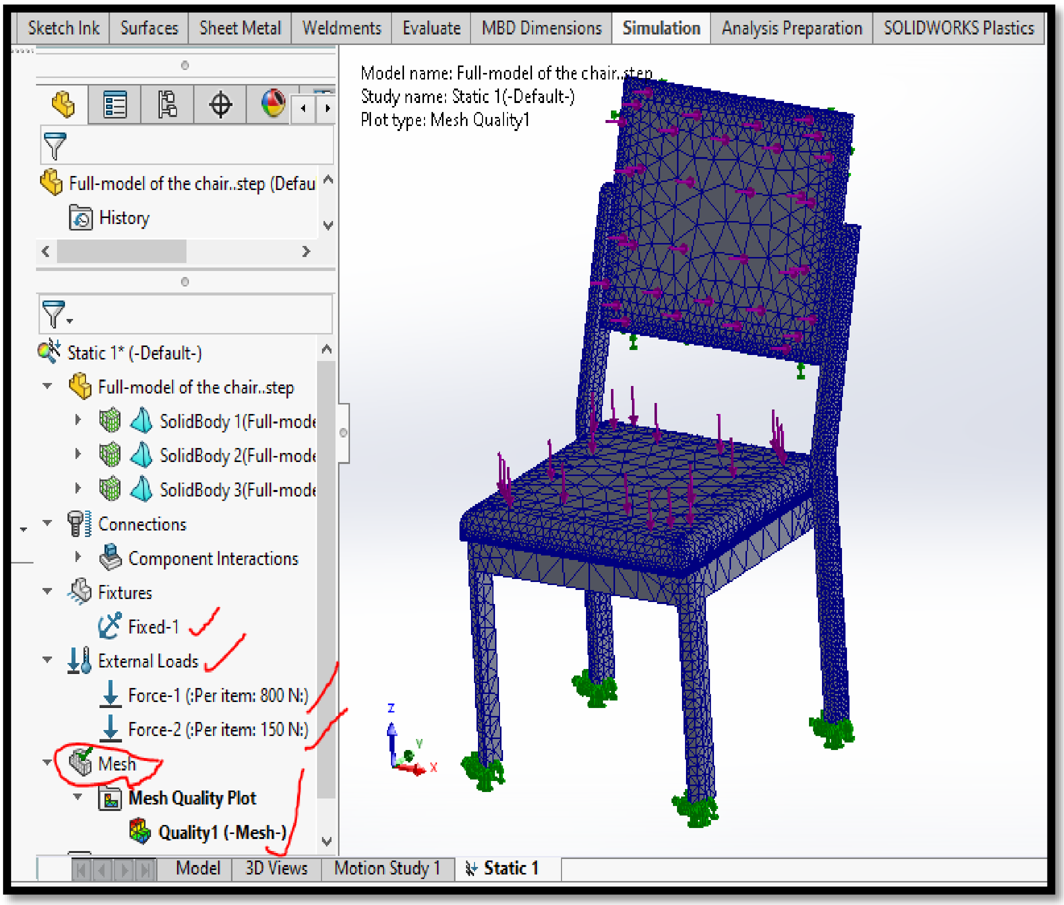


Figure 3.24: Mashing generated for the selected sewing chair mode

Table 3.18: Mashing generated information for the selected sewing chair model

Mesh type	Solid Mesh
Mesher used:	Blended curvature-based mesh
Jacobian points for high quality mesh	16 Points
Maximum element size	54.0261 mm
Minimum element size	2.70131 mm
Mesh quality	High
Total nodes	69620
Total elements	39657
Maximum aspect ratio	34.349
% of elements with aspect ratio < 3	98.8
Percentage of elements with aspect ratio > 10	0.00504
Percentage of distorted elements	0
Time to complete mesh (hh:mm:ss)	00:00:13

3.4.3.7 Running the Study

Simulation prepares the model for analysis and then calculates stress, displacements, strain, and factor of safety (FOS). At this stage, a static analysis was conducted using a FEA of the studied part (the selected sewing chair model), with default settings for the finite element and mesh density. For these elements, either the default settings or modified settings can be used, as described by Iancu, (2017). These settings were applied for the simulation and analysis, as shown in Figure 3.25. Furthermore, a linear static analysis was performed on the selected sewing chair model to determine the maximum stress and strain. This is essential because, before fabricating a design, the designer and engineer need to understand the performance of the object to be fabricated. It also helps to prevent potential issues. For instance, fabricating an object without understanding its performance may result in wasted energy and money, as the object may not meet the desired specifications. Therefore, conducting a simulation test on the redesign in SolidWorks can help avoid unwanted occurrences.

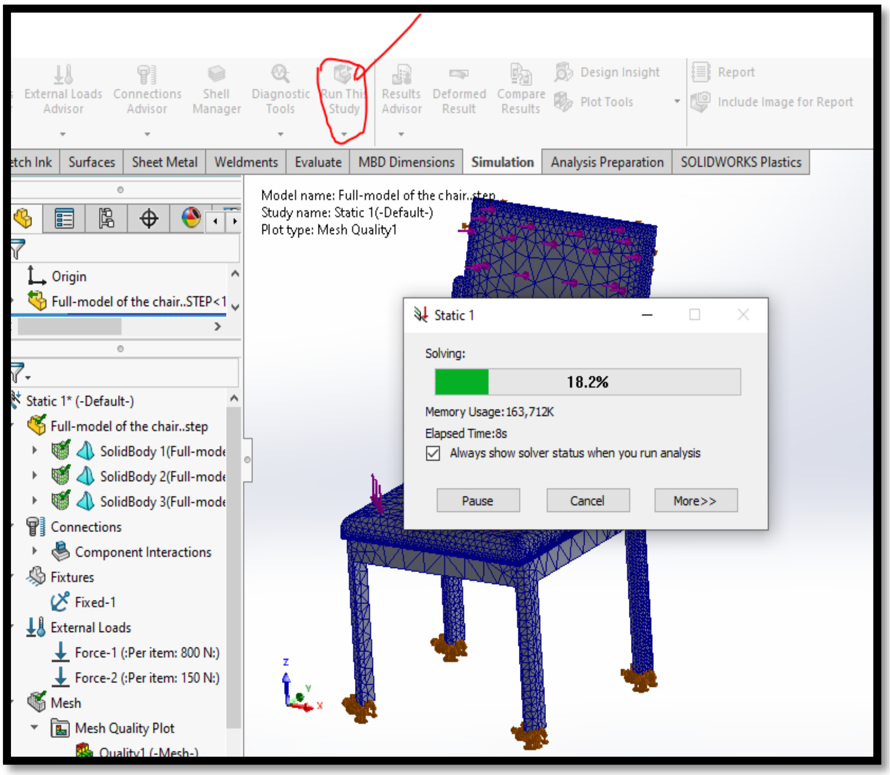


Figure 3.25. Running the static analysis for selected sewing chair model by FEA

3.4.3.8 Viewing the Study Results

After successfully conducting a study for the FEA analysis, the results were examined for the sewing workstation (selected sewing chair) model, focusing on stress, strain, displacement, and FOS results. Figure 3.26 displayed the study results for the FEA static analysis.

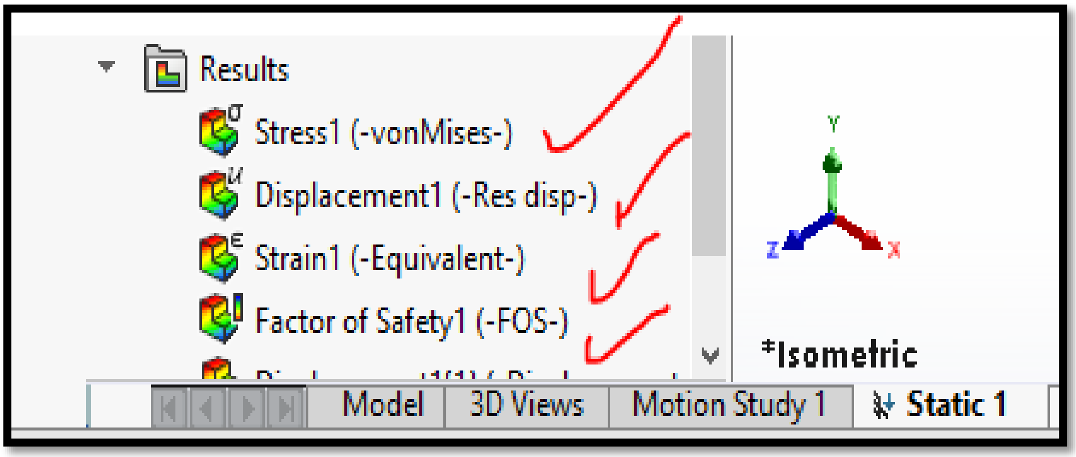


Figure 3.26: Viewing the study results

3.4.3.9 Simulation Advisor

The simulation advisor is a collection of tools that assist designers in the analysis process by answering a series of questions. These tools gather the necessary data to enable designers to conduct their analysis. The simulation advisor operates with the SolidWorks simulation interface by initiating the appropriate property managers and linking to online help topics for further information, as illustrated in Table 3.19 and Figure 3.27.

Table 3.19: Simulation advisor

Simulation advisor	Helps designer define sensors and creates studies automatically.
Bodies and materials advisor	Let's designer specify how to treat bodies within a part and apply materials to components.
Mesh and run advisor	Helps designer specify the mesh and run the study.
Results advisor	Provides tips for interpreting and viewing the output of the simulation.

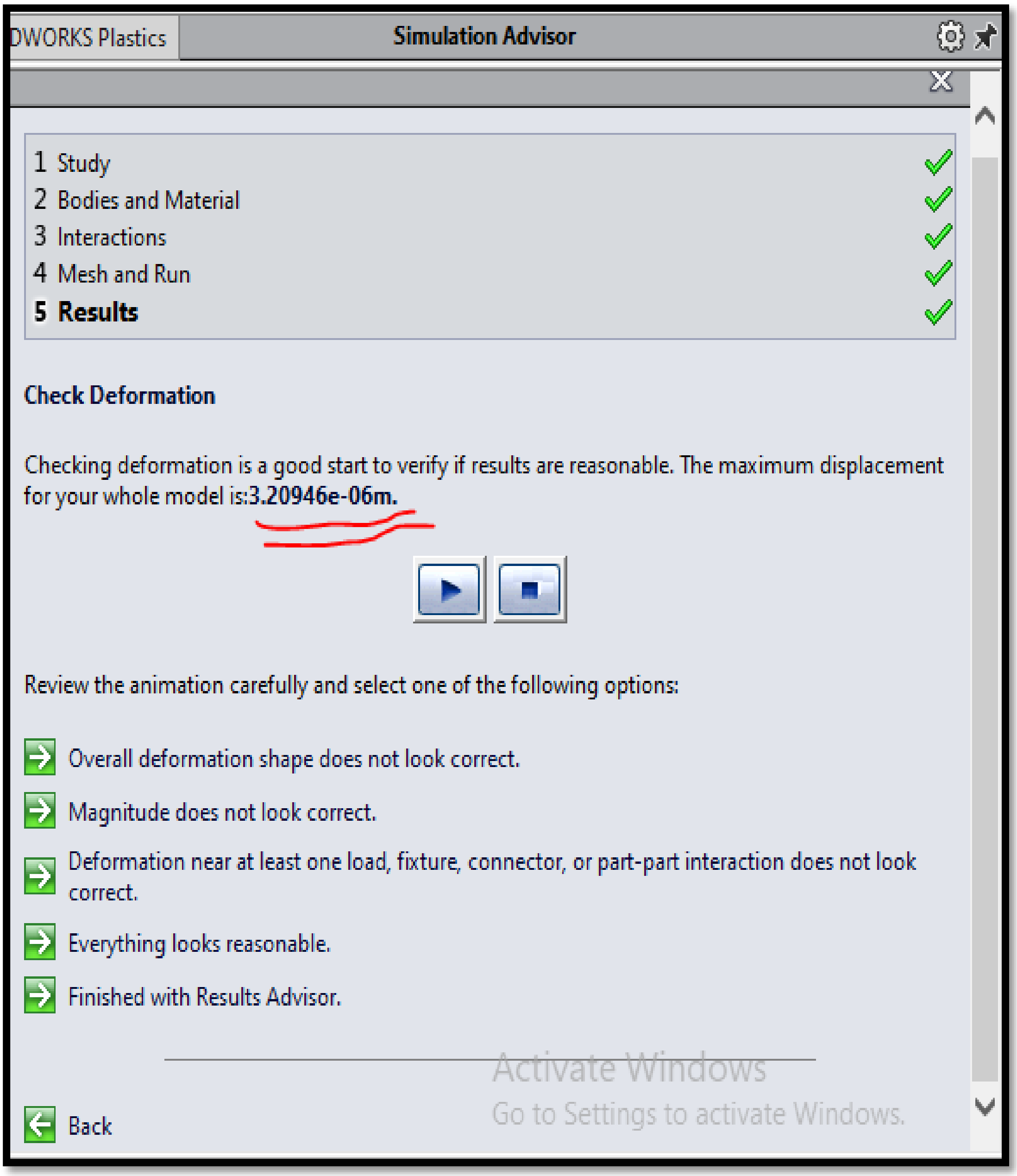


Figure 3.27: Simulation advisor

3.5 Optimising the Redesign of Workstations for Garments-Making Workers at the Sewing Operation

3.5.1 Introduction

The fifth specific objective of this research is to optimise the redesign of workstations for garment-making workers in the sewing operation. Utilising the collected anthropometric data, a worker's sewing workstation was modeled, simulated, and optimised. The optimisation analysis is part of the redesign study conducted in SolidWorks simulation, a program frequently used in the industry. The design study model is a powerful feature that is not widely utilised. This model allows users to quickly adjust a solid model's parameters across a grid of predetermined values and measure one or more critical outputs. Furthermore, advanced users can rapidly iterate geometry to perform FEA and optimise for mass and thermal properties. Previous studies by Iancu, (2017), and Iancu & Gutsalenko, (2019) indicated that a study can be conducted using either simulation express or simulation model, which enables a reduction in time to market by decreasing the number of product development cycles. Additionally, the design can be optimised simultaneously, thus reducing costs by testing the model on the computer rather than through laboratory tests.

Moreover, the SolidWorks simulation, including simulation express, simulation, and design study, is an enhanced version of a feature from simulation express. This tool can help reduce costs and time to market by allowing designs to be tested on the computer instead of relying on expensive and time-consuming field tests. Without utilising an optimisation study, achieving the best part design typically requires costly and lengthy product development cycles. Consequently, researchers usually need to first create the model in the SolidWorks system, prototype the design, test the prototype in the field, evaluate the results of the field tests, and modify the design based on those results. This process can continue until a satisfactory solution is achieved. Conversely, using SolidWorks models (SolidWorks Simulation Express/Simulation/Design Study) for preliminary studies can facilitate tasks such as testing the model on the computer rather than through field tests. Thus, there are benefits in reducing costs and time to market by minimising the number of product development cycles and optimising designs by simulating concepts and scenarios before making final decisions (Iancu & Gutsalenko, 2019).

The optimisation analysis is a component of the design study within the SolidWorks simulation. This simulation can determine the optimal dimensions for most features in the SolidWorks model based on results such as stress, strain, displacement, and factor of safety. After conducting a stress analysis, strain analysis, displacement analysis, and factor of safety assessment, the optimisation analysis is performed to identify the optimal value for a specific model dimension while adhering to a defined criterion. For example, to find the optimal length of a part, the maximum stress should not exceed a specified limit. The design study is a feature of the SolidWorks system that can help achieve the aforementioned goals. There are two primary modes for conducting a design study: The first mode is evaluation, where discrete values are specified for each variable, and sensors are used as constraints. The CAD software executes the study using various combinations of these values and reports the output for each combination. The second mode is optimisation, which utilises values for each variable, either as discrete values or within a range. Additionally, sensors can serve as constraints or goals. The CAD software performs iterations of the values and reports the optimal combination to meet a specified goal (such as minimum mass). Furthermore, to achieve the fifth specific objective, the entire methodology can be divided into the following steps, as illustrated in Figure 3.28.

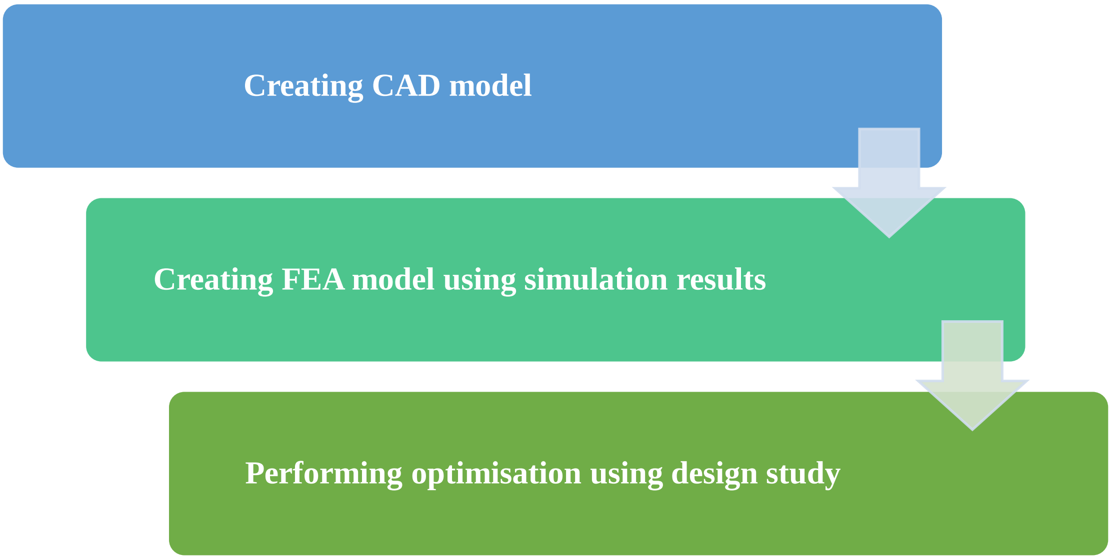


Figure 3.28: Main steps of the optimisation sewing workstation redesign methods

3.5.2 Creating the Model Using SolidWorks

The design of the chosen sewing chair was developed using SolidWorks for optimisation.

3.5.3 Creating the Finite Element Analysis (FEA) Model Using Simulation Results

The results of FEA were utilised to create the optimal model. For this optimisation, the objective function is defined as minimising the material volume needed for the final product of the chosen sewing chair redesign. Furthermore, in the context of sewing production, this leads to cost savings (less material, reduced machining, lower energy consumption) and is environmentally friendly (less waste, easier recycling at the end of the product's life).

3.5.4 Performing Optimisation Using Design Study

After the simulation of the model is complete, the next steps involve optimising the selected sewing chair's modeled part. This option enables the optimisation of a model's dimensions based on specified criteria and constraints. SolidWorks performs dimensional optimisation rather than shape optimisation, using it as an objective function to minimise mass. Upon completing a stress analysis, the optimisation analysis is employed to determine the optimal values for the selected sewing chair model's dimensions while satisfying the specified criteria. A design study can address a variety of CAD challenges. Additionally, the designer and engineer can resolve the following issues using SolidWorks (Iancu, 2017):

1. The designer and engineer can define multiple variables using any simulation parameters or global driving variables.
2. The designer and engineer can utilise sensors to establish a variety of constraints.
3. The designer and engineer can create several objectives through the use of sensors.
4. Designers and engineers can analyse models without considering the outcomes of simulations. For example, they can use the variables of density and model dimensions along with the constraint of volume, and also minimise the mass of an assembly.
5. The designer and engineer can evaluate design decisions by defining a parameter that directs bodies to utilise variables specifying materials.

These sections outline the basics of establishing and executing an optimisation. Additionally, the flowchart illustrating the essential steps for conducting the optimisation process through a design study is shown in Figure 3.29.

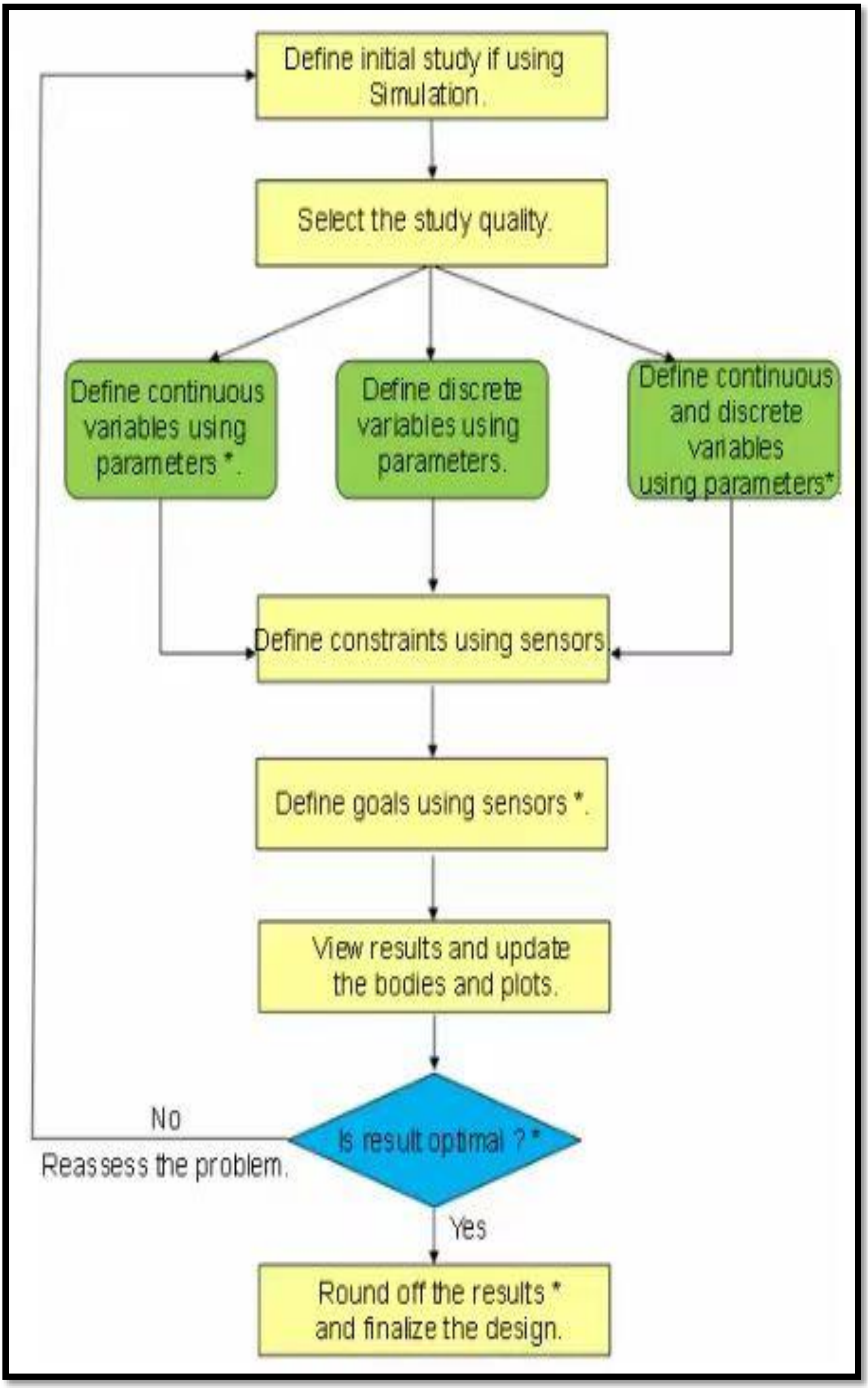


Figure 3.29: Flowchart of the optimisation using design study

To optimise using a design study, the following steps are taken (Iancu, 2017):

3.5.4.1 Defining Initial Simulation Studies

The designer and engineer must conduct at least one preliminary study when using simulation data sensors in a design study. These initial studies lay the groundwork for the optimisation process, evaluation, and the program executes these studies with various variables during each iteration.

3.5.4.2 Evaluating the Results of the Initial Studies

If the designers and engineers utilise simulation studies in the design process, evaluating the results of the preliminary studies will aid in defining the optimisation program. Furthermore, examining the specifics, the designer intends to use constraints as beneficial.

3.5.4.3 Setting the Properties of an Optimisation

Setting the properties for optimisation was accomplished during the optimisation phase, as shown in Table 3.20 and Figure 3.30. Additionally, the study quality in the property manager under design study quality was chosen. Likewise, a folder for the default location in the results directory was selected.

Table 3.20: Setting the properties of an optimisation

Study name	Design study 1
Analysis type	Optimisation
Design Study Quality	High quality (slower)
Result folder	SolidWorks document: Selected sewing chair model

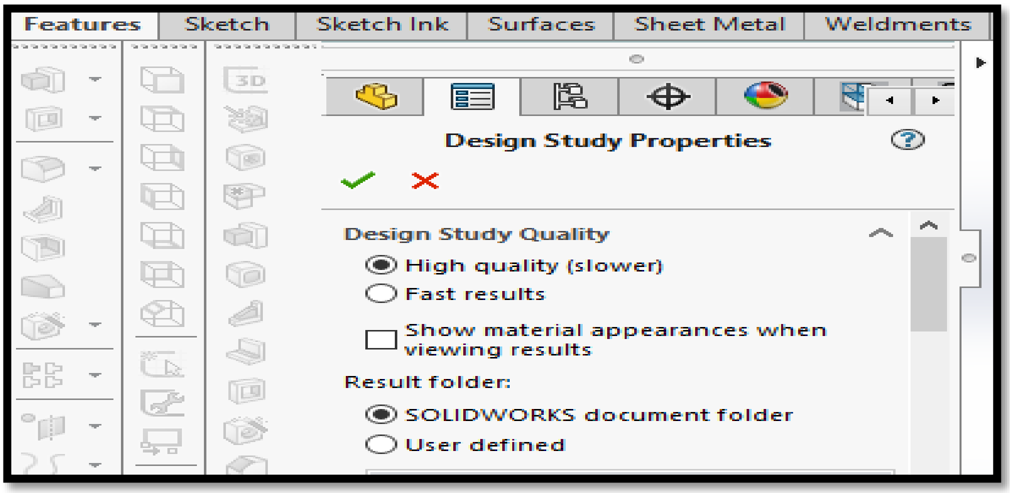


Figure 3.30: Setting the properties of an optimisation

3.5.4.4 Starting a Design Study for Optimising the Model

The new design study has commenced, and a design study tab now appears at the bottom of the graphics area, as shown in Figure 3.31.

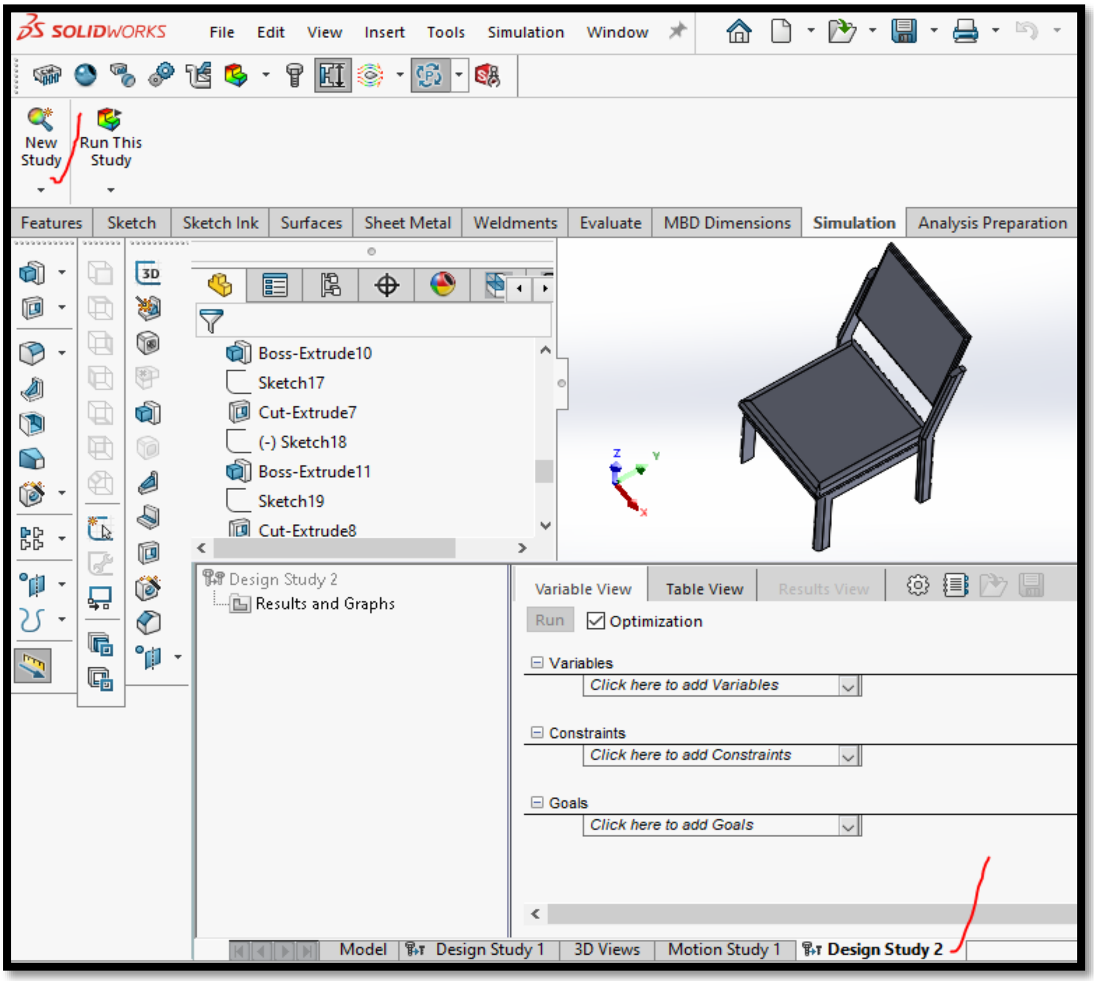


Figure 3.31: Starting a design study for optimising the selected sewing chair

3.5.4.5 Defining Variables

To conduct an optimisation, the continuous variables were defined. These continuous variables are not suitable for evaluating the optimisation, which serves as an introductory version of the optimisation tools available in SolidWorks. This means that one can analyse only one variable at a time, which can be defined across several parameters to be used as design variables. In the optimisation, under variables, input the minimum and maximum values, which represent the allowable limits for the dimension. When specifying these values, ensure they do not contradict other relationships defined in the model. In the graphics area, a model dimension (design variable) was selected for optimisation. The model dimension appears in the add parameters dialog box as a defined design variable: 416.5 mm for seat height, with a minimum value set to 411.5 mm and a maximum value set to 421.5 mm, with a step of 1 mm; 462 mm for seat depth, with a minimum value set to 457 mm and a maximum value set to 467 mm, with a step of 2 mm; and 477.8 mm for seat width, with a minimum value set to 472.8 mm and a maximum value set to 482.8 mm, with a step of 3 mm to achieve optimal results for the model. The defining variable for the optimisation is shown in Table 3.21 as well as in Figure 3.32.

Table 3.21: Defining variables for optimisation

Name	Model dimension	Type	Value	Units
Seat height	416.5	Range with step	*Min: 411.5* *Max: 421.5* *Step: 1*	*mm*
Seat depth	462	Range with step	*Min: 457* *Max: 467* *Step: 2*	*mm*
Seat width	477.8	Range with step	*Min: 472.8* *Max: 482.8* *Step: 3*	*mm*

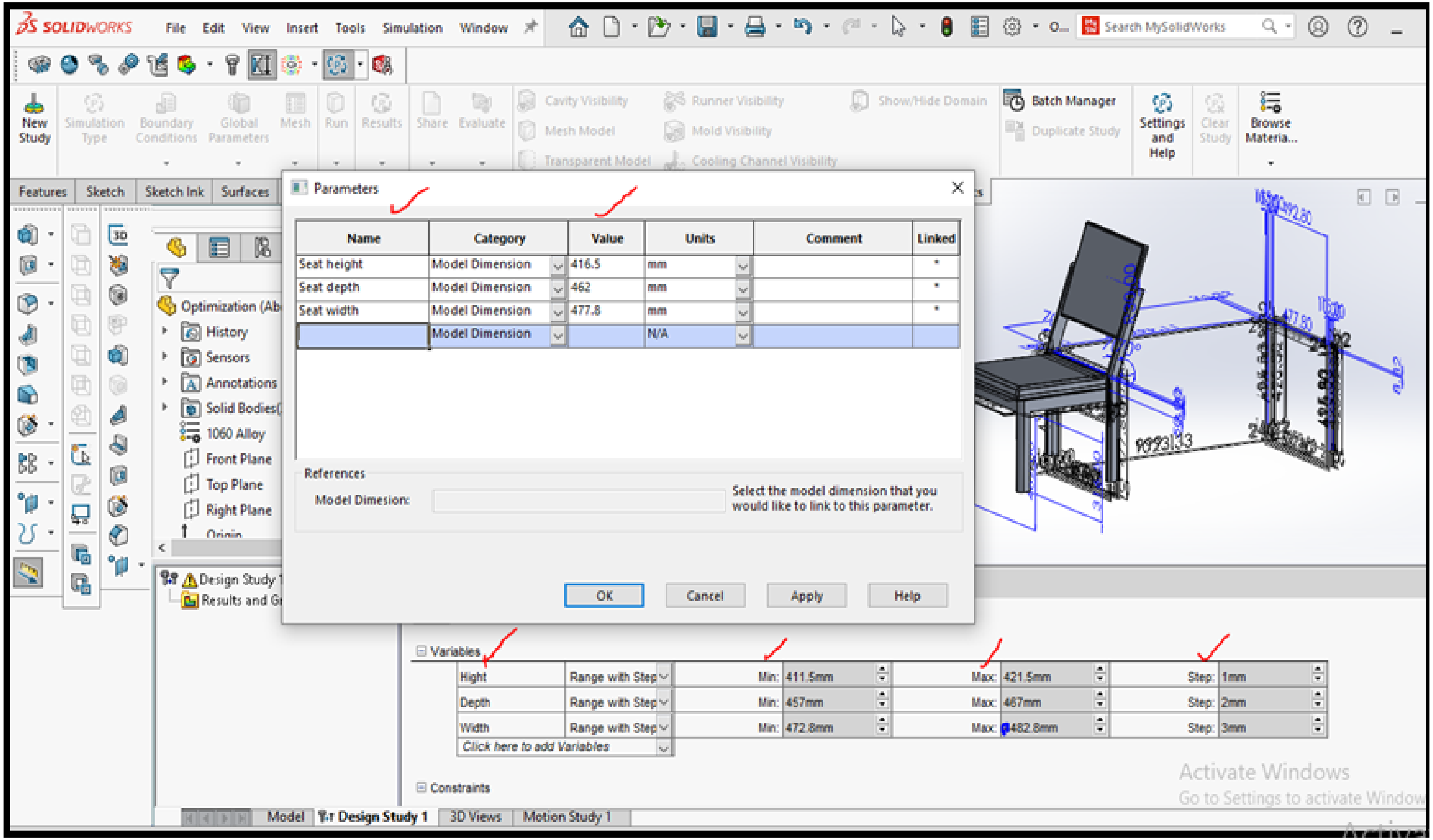


Figure 3.32: Defining variables for optimisation

3.5.4.6 Defining Constraints

The constraints were established to outline the requirements that the design must fulfill, and the global variables or sensors may regulate the mass characteristics, dimensions, and simulation data. The maximum stress value can be specified; thus, a constraint was defined for the compressive stress, set at 10 times less than the yield limit for the selected material (Aluminum alloy 1060), which is 27,570 MPa, as shown in Table 3.22 and Figure 3.33.

Table 3.22: Defining constraints for optimisation

Sensor name	Condition	Bounds	Units	Study name
Stress 4	Is less than	Max: 27570	MPa	Static

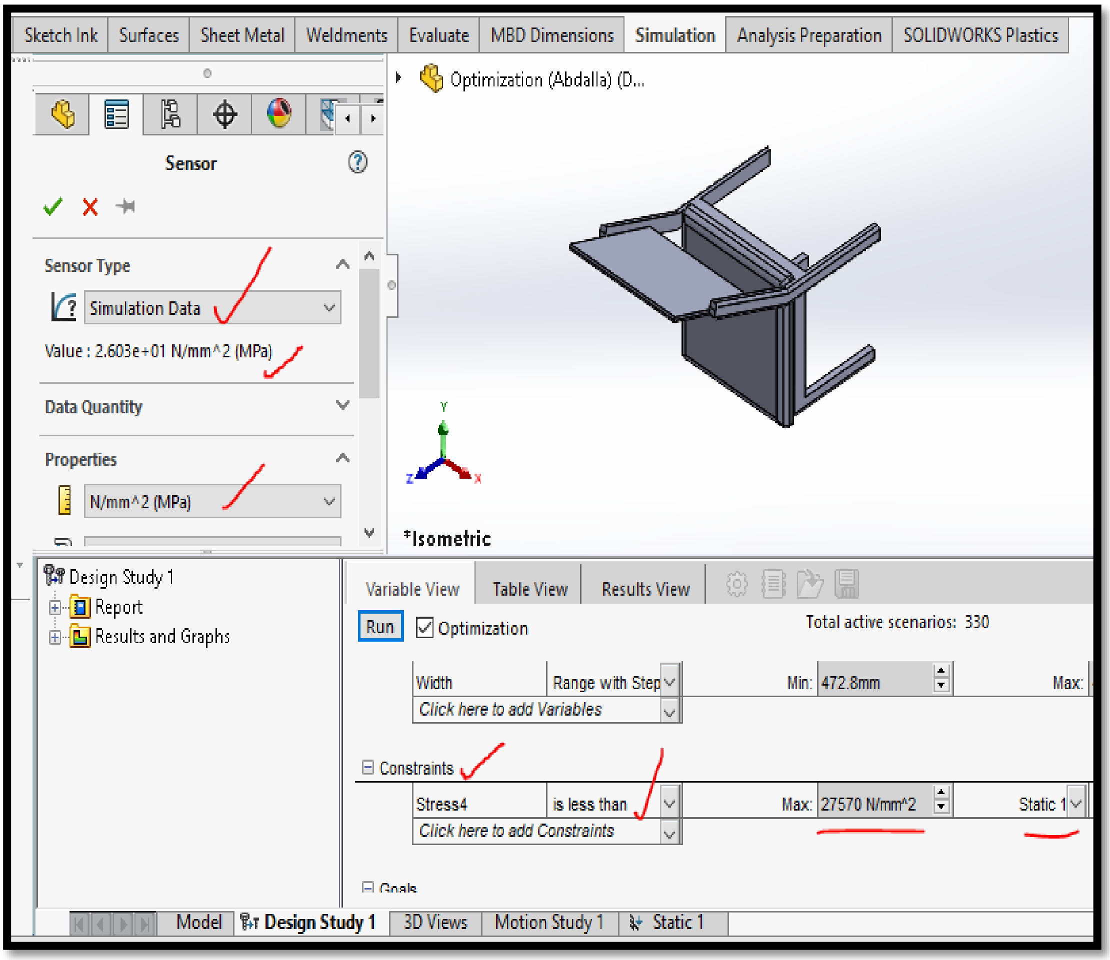


Figure 3.33: Defining constraints for optimisation

3.5.4.7 Defining Goals

The goals were established for optimisation to clarify the objective functions. Based on these goals, sensors were chosen according to mass properties such as mass, volume, surface area, and center of mass. In the SolidWorks simulation, the main objective is to reduce the mass by a factor of ten, as illustrated in Table 3.23 and Figure 3.34. It can be noted that for the selected variables and the increasing steps, there are a total of 330 potential active scenarios.

Table 3.23: Defining goals for optimisation

Name	Goal	Properties	Weight	Study name
Mass 2	Minimising	Mass	10	-

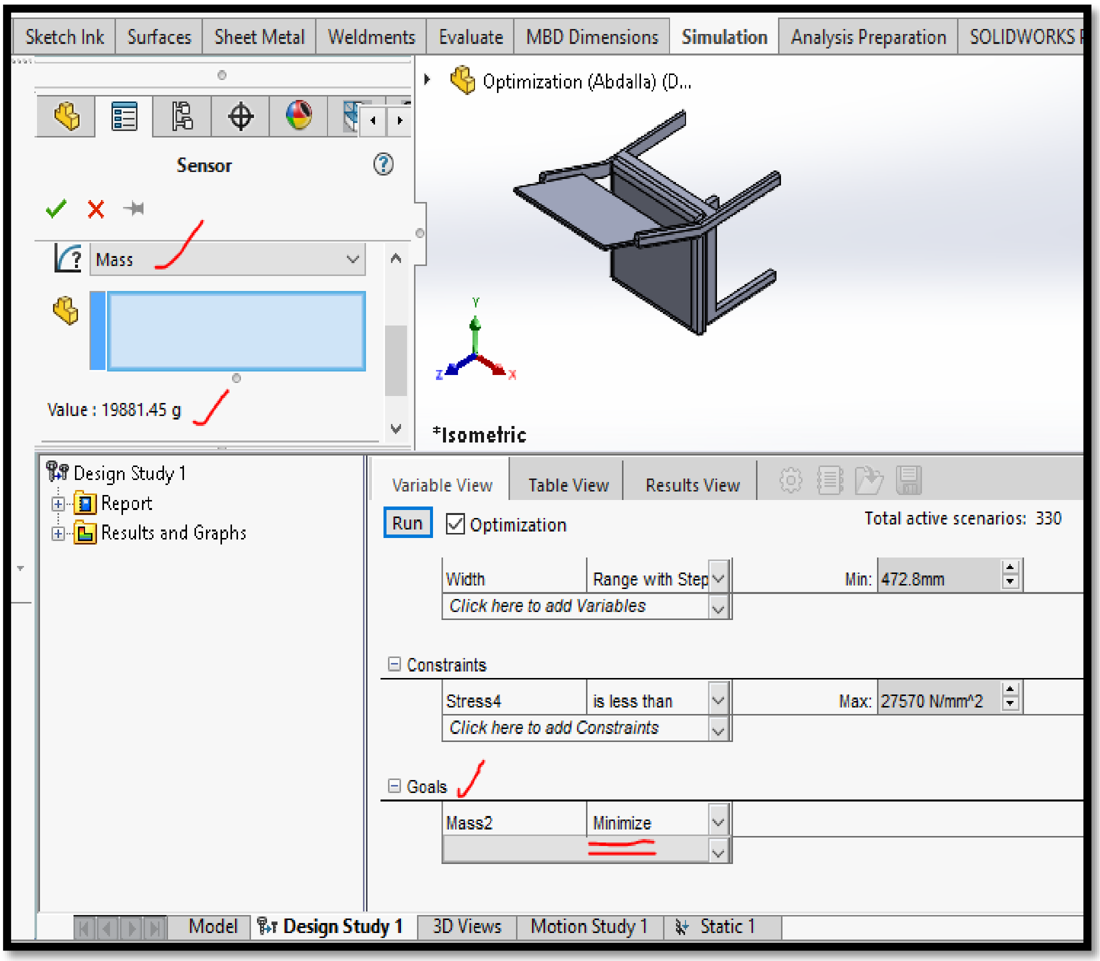


Figure 3.34: Defining goals for optimisation

3.5.4.8 Running the Study

The optimisation runs, necessitating a certain number of iterations. The results appeared in the results view, and the model was updated to reflect the optimal value. Additionally, in the simulation wizard for the optimisation, the initial value was selected to reset the parameter to the original value in the chosen sewing chair model. Furthermore, the optimal value was selected to set the parameter to the optimised value. It can be observed that for the selected variables and the increasing steps, there were 332 possible active scenarios that ran successfully, as shown in Figure 3.35.

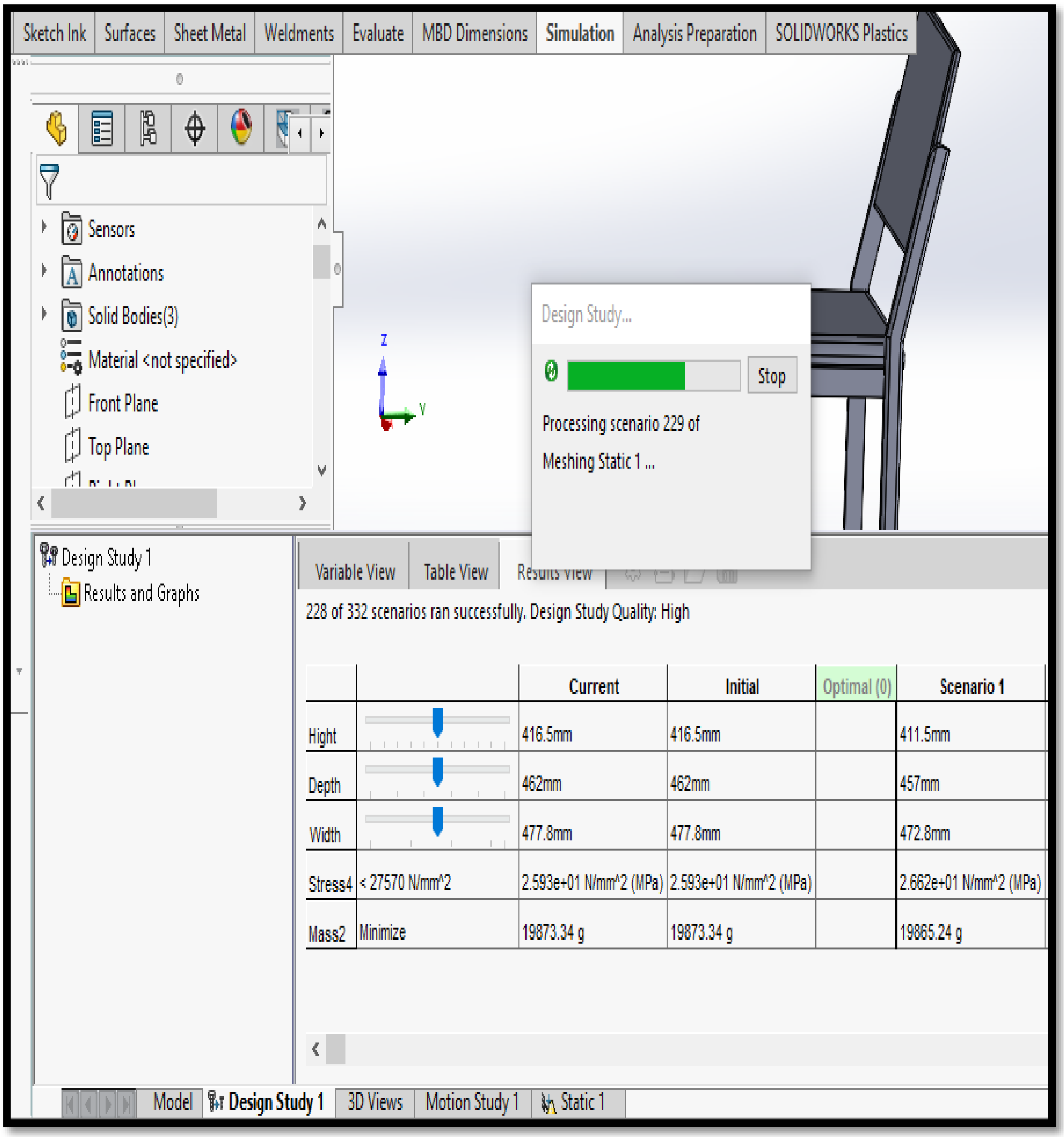


Figure 3.35: Running the study for optimisation

3.5.4.9 Viewing the Results of the Optimisation

The optimisation findings were derived by selecting the results view table. Upon clicking the results view table, all 332 scenario variables were incorporated into the model of the ergonomic sewing chair in the graphics window, as illustrated in Figure 3.36.

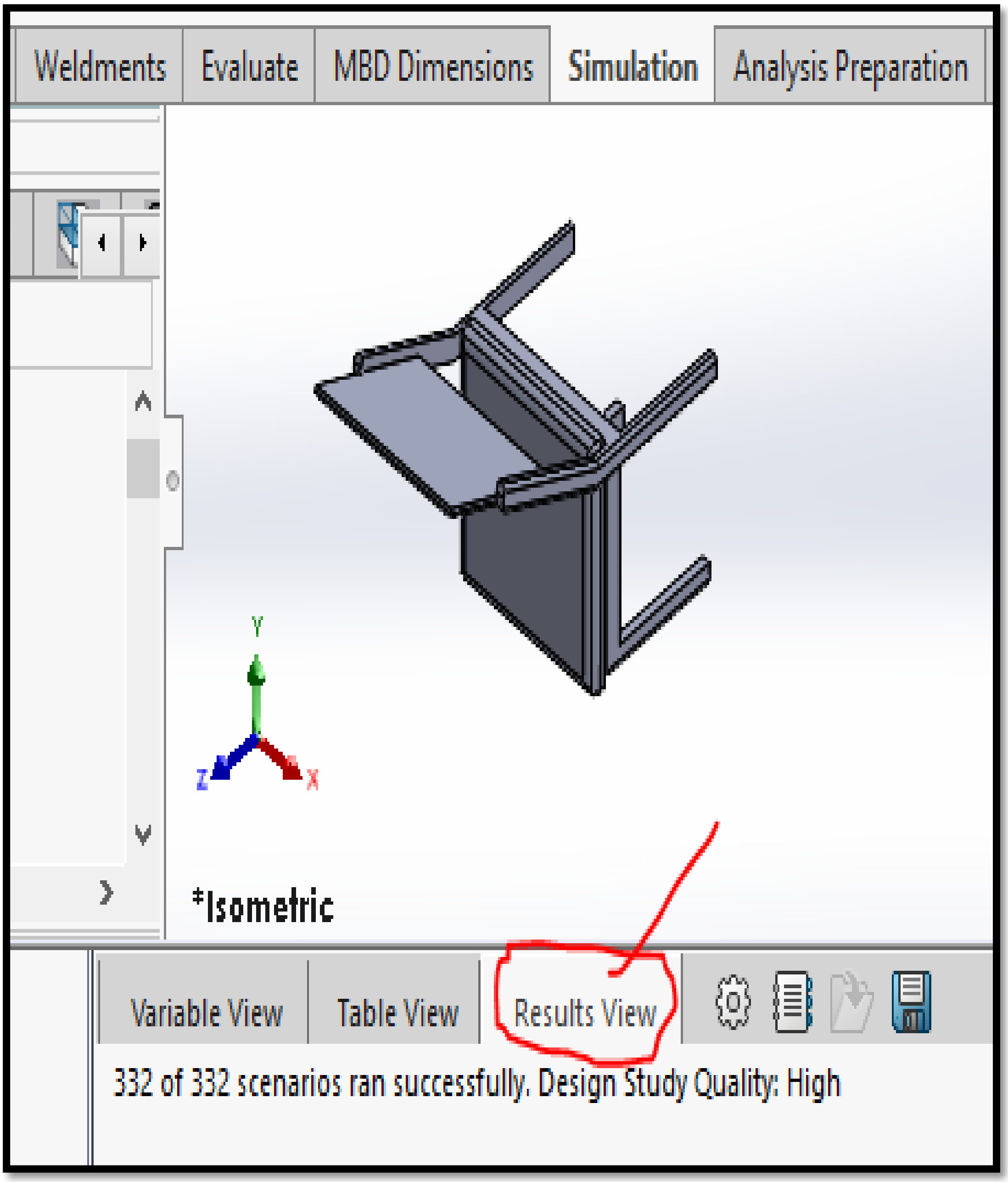


Figure 3.36: Results view

3.5.4.10 Optimisation Outcomes

The assessment of the optimisation should refrain from using continuous variables, as a range of variable values cannot sufficiently define the discrete scenarios.

3.5.4.11 Creating Design Scenarios by Modifying the Design Variables

Creating design scenarios by modifying the design variables is a vital step in performing optimisation in SolidWorks. This allows the designer to explore various design alternatives and evaluate their performance under different conditions. There are specific steps for creating design scenarios in SolidWorks, which are (SolidWorks, 2010):

1. Identifying the design variables that the designer wants to change: The design variables can include dimensions, material properties, and other parameters that affect the behavior of the model. Identifying which variables to change allows exploration of different design options.
2. Defining the range of values for each design variable: This can be done manually or by using the design table feature in SolidWorks.
3. Creating the design scenarios: Utilise the design study feature to create multiple scenarios with different combinations of the design variable values. Each scenario represents a distinct design option that the designer wishes to evaluate.
4. Running the simulation for each scenario: For each design scenario, the designer must run the simulation and collect the results. This can be done automatically using the design study feature in SolidWorks.
5. Analysing the results: Once the results have been collected for each design scenario, analyse the data and compare the performance of each design option. This can help designers identify the best design option for their thesis, dissertation, and project.

3.6 Fabricating the Redesign of Workstations for Garments-Making Workers at the Sewing Operation

3.6.1 Introduction

The sixth specific objective of this research is to fabricate a redesign of workstations for garment-making workers at the sewing operation. Following this, simulation and optimisation were conducted on models of the sewing work to achieve an ergonomically suitable workstation for the workers. The work was furthered by fabricating and manufacturing the proposed model and validating the redesign of the sewing workstation through experimental tasks. The fabrication process commenced after the redesign, simulation, and optimisation of the sewing workstation. This process involves the fabrication of all parts that have been redesigned according to the dimensions using various manufacturing methods. The fabrication process includes: material selection, measuring, cutting, drilling, grinding, assembling, welding, painting, and finishing. To accomplish the sixth specific objective, the entire methodology can be divided into the following steps, as illustrated in Figure 3.37.

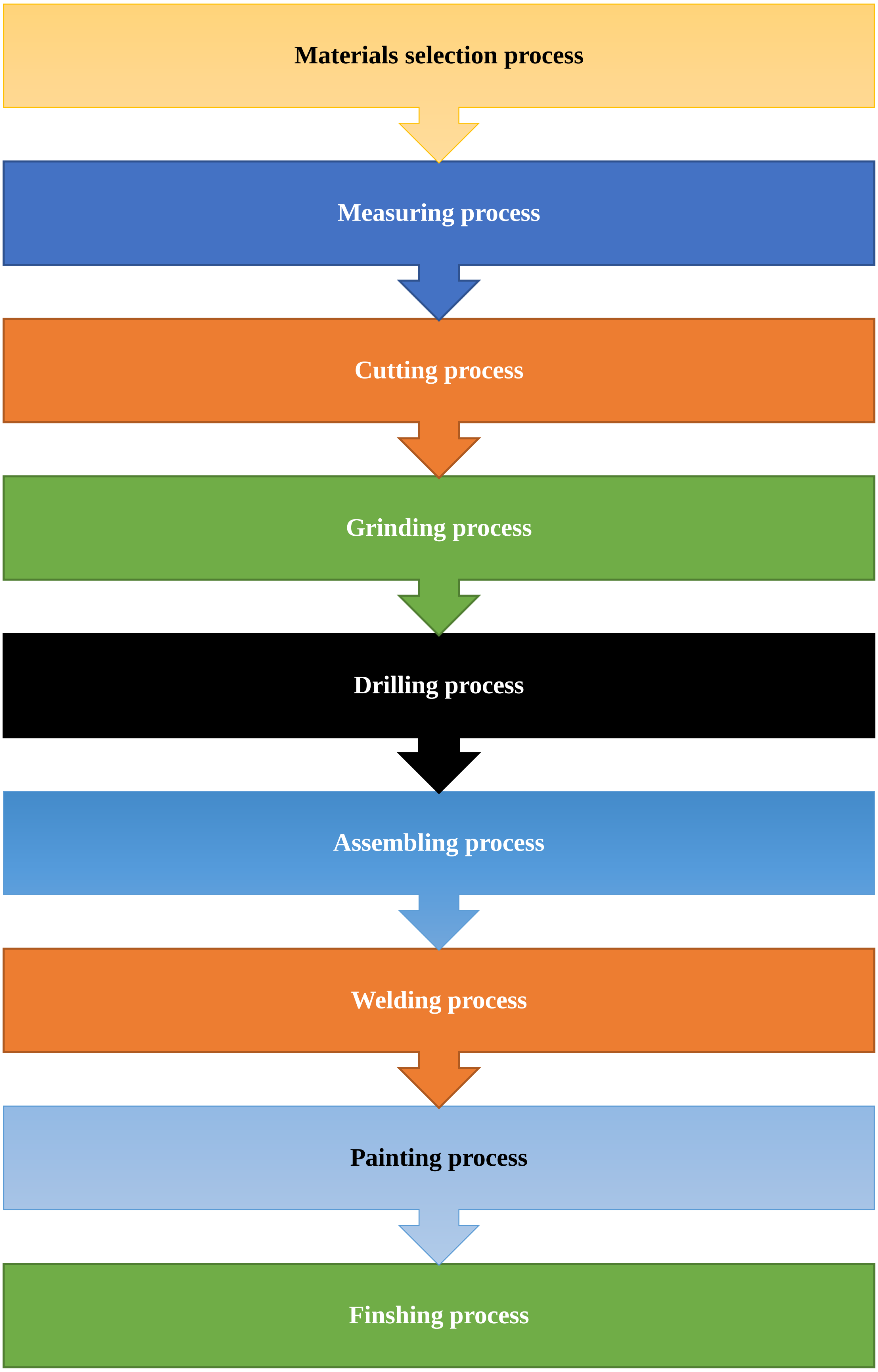


Figure 3.37: Main steps of the fabrication process of the sewing workstations redesign

3.6.2 Fabrication Process

In creating the ergonomic redesign of the sewing workstation, particularly the sewing chair and adjustable sewing machine table, several fabrication processes must be employed, including:

3.6.2.1 Materials Selection Process

The properties considered in the material selection were limited to: the technical properties of the materials, such as conductivity, density, strength, etc.; the manufacturing aspects, including ease of production with existing facilities; the economic properties, like material cost, production expenses, and availability; and the ecological properties, such as recycling capability and sustainability (Madara et al., 2016). The materials selection was done according to Miller, (1989). Aluminum alloy 1060 was chosen for the fabrication of a sewing workstation because it is currently the most widely used metal in the furniture industry due to its lightweight, competitive cost, corrosion resistance, and excellent working properties, particularly for molded metal sewing chairs. Metal remains the preferred material for sewing furniture due to its contemporary appearance, charm, and character. Meanwhile, wood was selected for the fabrication of an adjustable sewing machine table because it is the most common material used in furniture (table) manufacturing and is comparatively low in cost. The selection of materials and their properties for each part is shown in Tables 3.24 and 3.25, respectively. Additionally, Table 3.26 presents the Bill of Materials (BOM) as the total parts or components required for the assembly of the worker's sewing workstation, which is to be fabricated with consideration of the redesign dimensions based on anthropometric data. In simple terms, the BOM is a list of all the parts needed to assemble a redesigned worker's sewing workstation. Typically, the BOM includes the item or part number, quantity/length per assembly, size, and specifications required per assembly. This BOM is primarily for the fabrication of the redesigned worker's sewing workstation.

Table 3.24: Materials selection for sewing workstation redesign

SI. No	Parts	Materials	References
1	Base seat and backrest seat	Polyvinyl Chloride (PVC) form	
2	Base support and Base frame	Aluminium Alloy 1060	Madara et al., (2016), and Miller, (1989).
3	Hardwoods for table	White wood oak (flat-sawn)	

Table 3.25: Materials Properties

Materials used	Mass density (Kg/m^3)	Yield strength (MPa)	Tensile strength (MPa)	Shear modulus (MPa)	Poison ratio
Aluminium Alloy 1060	2700	27.57	68.94	27000	0.33
PVC foam	60	26.6	-	70	3
Woods oak	560	-	-	-	-

Table 3.26: Bill of Materials (BOM)

No.	Material	Size	Quantity/Length
1	Furniture paint	2 liters	2 pes
2	Flat washers	14 mm	3 pes
3	Aluminium Alloy 1060	1in * 1.5 mm	2 pes/20 ft
4	PVC foam	2 m^2 * 3 in	2 pes/2 m
5	Custom leather upholstery	2 m^2 * 3 in	2 pes/2 m
6	Thinner	3 liters	1 pes
7	White wood oak (flat-sawn)	4 ft * 8 ft * 1 in	2 pes
8	Hinges	¾ in	12 pes
9	Nuts	1 * 3/4 * 8 mm	12 pes
10	Screws	2 * ¾ in * 3 mm	12 pes
11	Nut for adjustability	M25*1 mm	1 pes
12	Tilting support for top table	170*10 mm	1 pes
13	Tilting bar for table top	330*30*2.6 mm	1 pes
14	Back support rods	460*21.3 mm	2 pes
15	L shape ruler metal	16 * 24 in	1 pes
16	Tilt control for chair design	7.9 * 5.8 in	1 pes
17	Protective glasses	ANSI Z87.1	1 pes
18	Steel marker pen	3-5 mm	1 pes
19	Metal tape measure	8 mm	1 pes
20	Goniometer	6/8/12 in	1 pes
21	Back support block board	430*300*19 mm	1 pes
22	Bag shelf metal sheet	920*530*1 mm	1 pes
23	Bag support angles	520*310*20 mm	1 pes
24	Wheel	2.5 in	1 pes

3.6.2.2 Measuring Process

The measuring process is the fabrication process that measures the materials cut to the proposed dimensions of the sewing workstation redesign (Qaidir & Abdillah, 2008). To measure the selected materials to the required dimensions, refer to the chosen sewing chair and adjustable sewing machine table redesign. This measuring process was conducted using an L-shaped ruler, measuring tape, and steel marker, as illustrated in Figure 3.38.

Figure 3.38: Measuring process

3.6.2.3 Cutting Process

The cutting process is a fundamental fabrication method in the manufacturing industry (Qaidir & Abdillah, 2008). The laser cutting machine, illustrated in Figures 3.39, was utilised to cut materials into parts according to the specified dimensions of the sewing workstation.

Figure 3.39: Cutting process using a laser cutting machine

3.6.2.4 Grinding Process

The grinding process is a fabrication and finishing process in manufacturing that involves less machining and offers high precision, making it widely used in the industry (Qaidir & Abdillah, 2008). The hand grinder machine, as shown in Figure 3.40, was used to adjust the materials of the sewing workstation redesign to ensure they meet the recommended dimensions of the proposed redesign. Additionally, Personal Protective Equipment (PPE) such as goggles, gloves, and safety boots were worn before the grinding process began.

Figure 3.40: Grinding process

3.6.2.5 Drilling Process

The drilling process is a crucial fabrication method that involves cutting to create holes with a circular cross-section in solid materials (Qaidir & Abdillah, 2008). The sewing chair and adjustable sewing machine table were marked and drilled using a drilling machine, following the dimensions of the redesigned sewing workstation, as illustrated in Figure 3.41.

Figure 3.41: Drilling process

3.6.2.6 Assembling Process

The assembly process is the culminating stage in fabrication, integrating all upstream processes of design, engineering, manufacturing, and logistics to produce an object that serves a specific function. The assembly process is illustrated in Figure 3.42.

Figure 3.42: Assembling process

3.6.2.7 Welding Process

The welding process is a fabrication technique that joins one part to another through a permanent connection (Qaidir & Abdillah, 2008). This task is performed using arc welding, as illustrated in Figure 3.43.

Figure 3.43: Arc welding process

3.6.2.8 Painting Process

The painting process is the final step in the fabrication of the sewing workstation redesign (Qaidir & Abdillah, 2008). This process begins with cleaning using sandpaper to remove all rust, followed by a thorough cleaning with thinner to ensure the sewing workstation redesign product is completely clean. The product was painted in a black/red oak colour and received two layers of paint. Once the painting process was complete, the sewing workstation redesign product was dried under the sun, as shown in Figure 3.44.

Figure 3.44: Painting process

3.6.2.9 Finishing Process

The finishing process in the fabrication of the sewing workstation redesign is a crucial part of the manufacturing process. In this finishing process, the final product of the sewing workstation redesign was created.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This fourth chapter of the thesis presents the findings and results discussed in the specific objectives outlined in the following sub-sections, as illustrated in Figure 4.1.

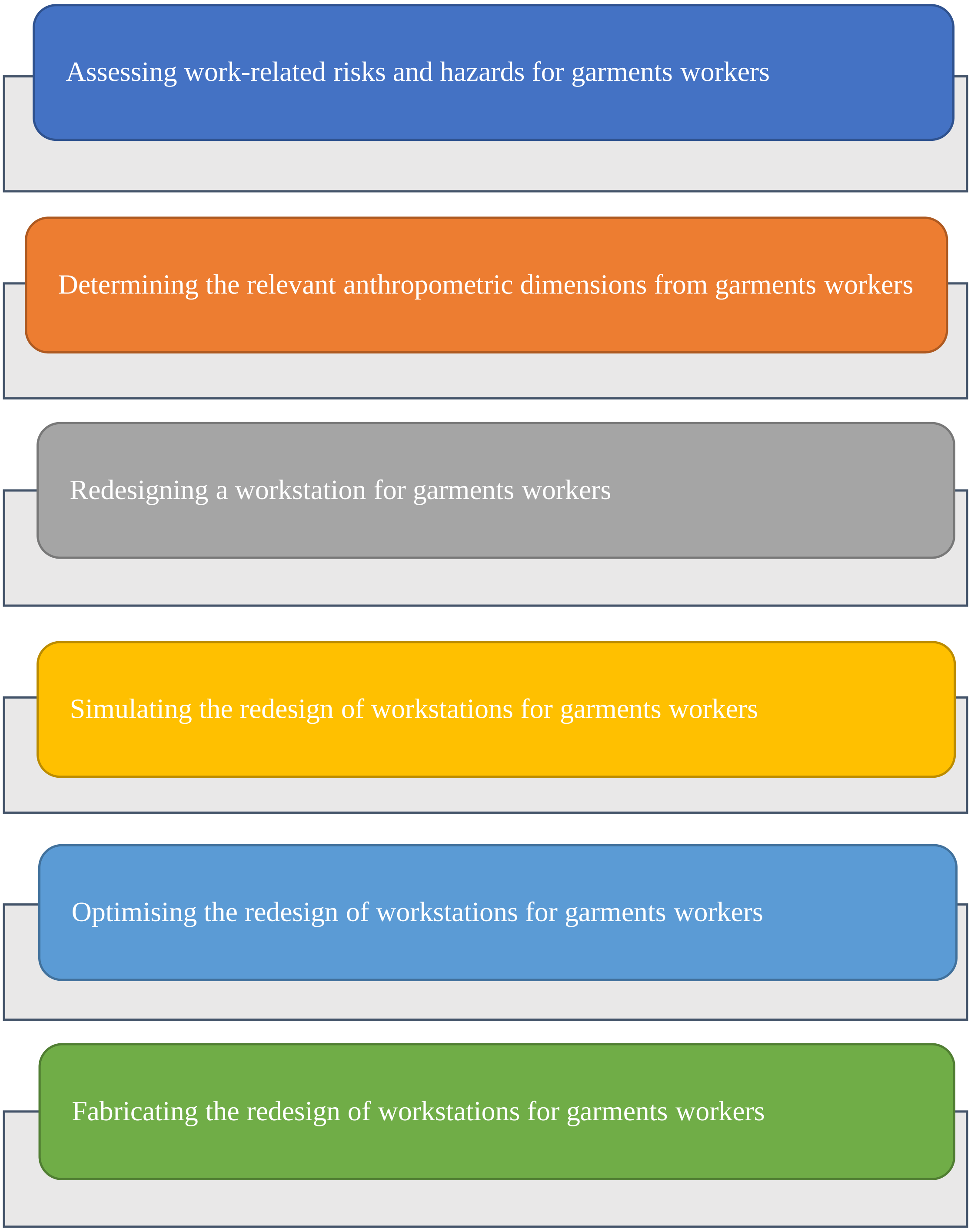


Figure 4.1: Results and discussions structure

4.1 Assessing Work-Related Risks and Hazards for Garments

The results of the work-related risks and hazards faced by garment-making workers at the sewing workstation are discussed in detail below:

4.1.1 Rapid Entire Body Assessment (REBA) Results

The processing of the worker's body posture data is conducted in the sewing workstation environment as part of the ergonomic redesign of the selected sewing chair workstation and adjustable sewing machine table for garment manufacturing. This involves marking a straight line along with the angles of the captured photos. Following the data processing, an analysis is performed, and the work body posture is scored using the REBA method. The body segments are categorised into two groups: group A and group B. Group A includes the neck, back, and knee, while group B comprises the upper arm, lower arm, and wrist. Additionally, based on the angle data of the body segments in each group, the scores for group A and group B can be determined. Based on the dimensions of the angles of the sewing worker's body parts: Group A (the score for neck movement was 2 at 28.07^0, which is > 20^0 flexion; the score for back movement was 2 at 16.93^0, which is between 0^0 - 20^0 flexion; and the score for knee movement was 2 at 73.23^0, which is > 60^0 flexion). See Table 3.1 in the methodology section. Group B (the score for upper arm movement was 2 at 28.86^0, which is between 20^0 - 45^0 flexion; the score for lower arm movement was 2 at 54.88^0, which is < 60^0 flexion; and the score for wrist movement was 2 at 35.12^0, which is > 15^0 flexion). See Table 3.2 in the methodology section. Figure 4.2 and Table 4.1 illustrate the body posture of the sewing worker who has been assigned a body posture scale. Based on the group A scores, using Table A in the methodology section (Table 3.4), it can be observed that the value of the Table A score is 4. The score for A is calculated by adding the Table A score of 4 to a load score of 0, resulting in a score of 4. Similarly, based on the group

B scores using Table B in the methodology section (Table 3.4), it can be seen that the value of the Table B score is 3. The score for B is calculated by adding the Table B score of 3 to a coupling score of 0, thus, the score for B is 3. Based on score A and score B, using Table C in the methodology section (Table 3.4), it can be seen that the value of score C is 4. The final REBA score is calculated by adding score C of 4 to an activity score of 1, resulting in a final REBA score of 5. In this study, the final REBA score for the existing design of the sewing workstation for garment manufacturing is 5, indicating that postures are at medium risk, corresponding to action level 2, and require necessary changes. Additionally, Table 4.2 and Figure 4.3 present the final REBA score for the existing design of the sewing workstation worker's posture.

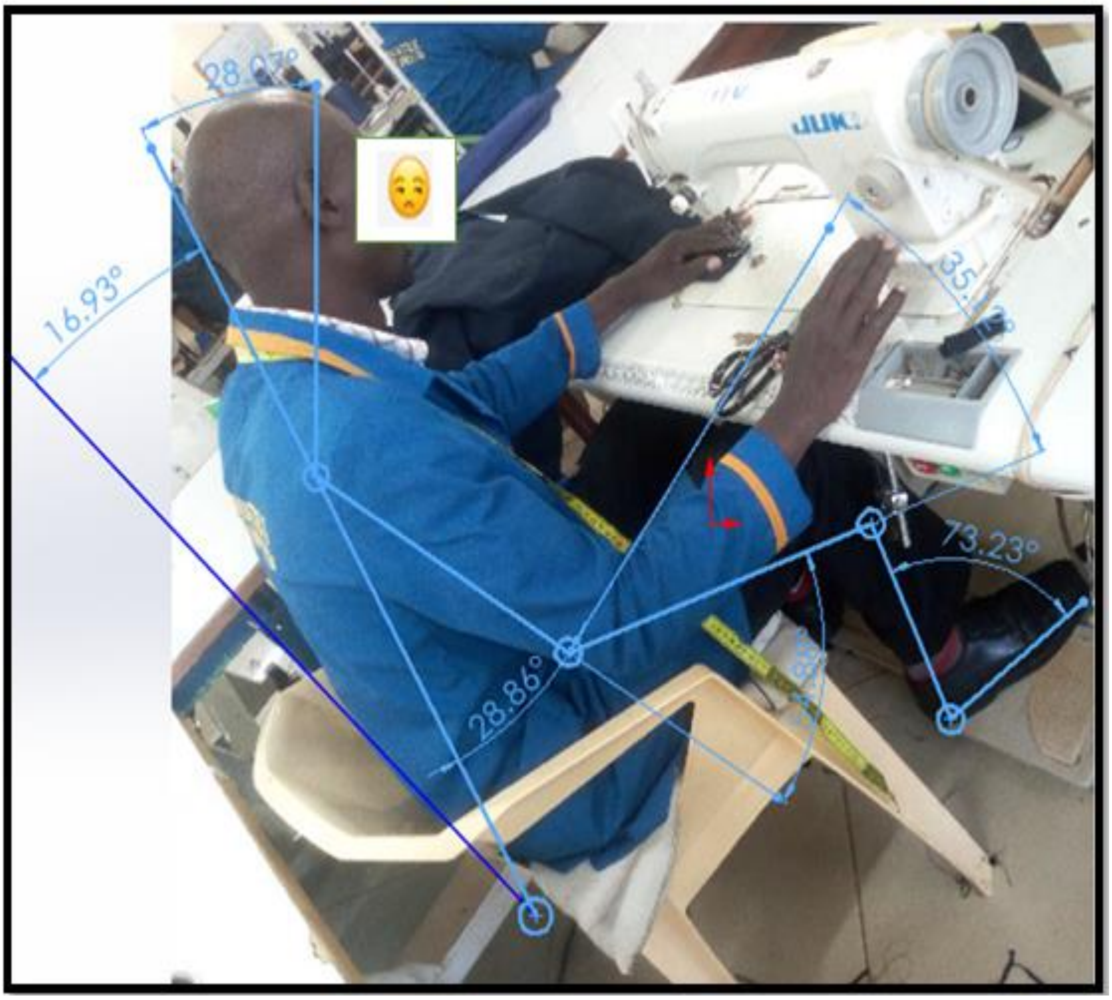


Figure 4.2: Sewing Worker’s body posture for ergonomic assessment

Table 4.1: REBA angle dimensions for sewing worker's body posture

Group	Dimensions	Angle
A	Neck	28.07^0
	Back	16.93^0
	Knee	73.23^0
	Load	0 kg
B	Upper arm	28.86^0
	Lower arm	54.88^0
	Wrist	35.12^0
	Coupling	0 kg

Table 4.2: REBA score on the sewing workstation worker's work posture

Group	Dimensions	Angle	Score	Table A	Score A	Score C	REBA score
A	Neck	28.07^0	2	4	4	4	5
	Back	16.93^0	2				
	Knee	73.23^0	2				
	Load			0			
Group	Dimensions	Angle	Score	Table B	Score B		
B	Upper arm	28.86^0	2	3	3		
	Lower arm	54.88^0	2				
	Wrist	35.12^0	2				
	Coupling			0			
	Activity score					1	

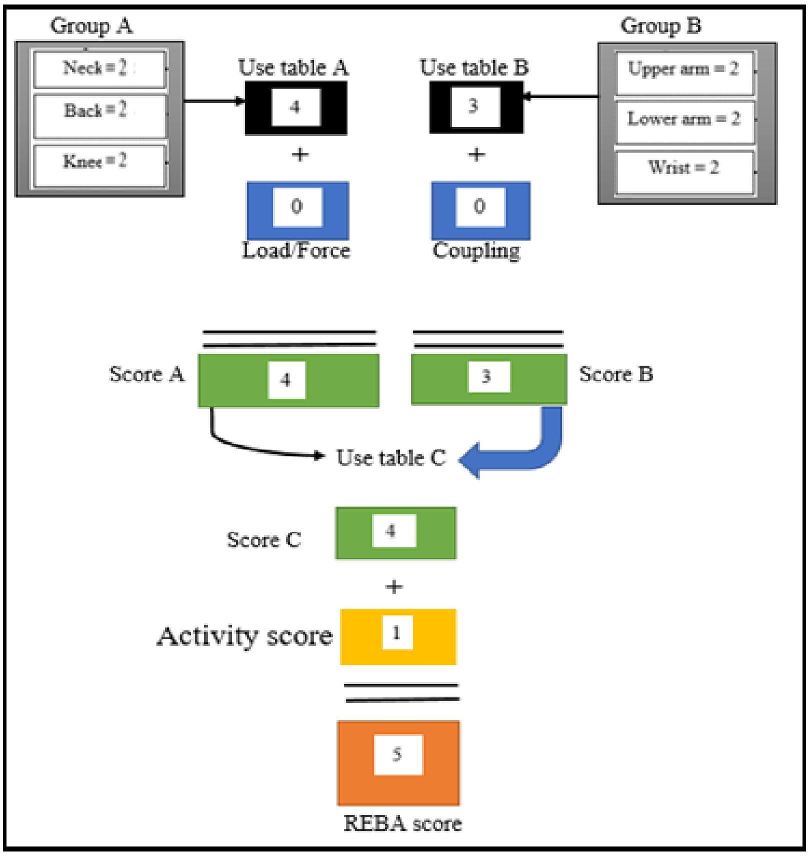


Figure 4.3: The REBA score sheet

4.1.2 Comparison of REBA results of the Present Study with the Previous Studies

The comparison of the REBA results from this study with previous research on work-related risks and hazards for workers in various industries is presented in Table 4.3. The current findings align more closely with those of Kusuma, (2020) and Shah et al., (2016), who reported a REBA score of 5 (medium level of risk requiring necessary changes) for workers at a single-head sandpaper machine and in garment manufacturing, respectively. Ahmad et al., (2021) determined that the final REBA score was 8 (high risk requiring immediate changes) for workers in the clothing industry. Earlier studies by Wibowo & Mawadati, (2021), AI Madani & Dababneh, (2016), and Beatrix, (2021) found a final REBA score of 11 (very high level of risk requiring immediate changes) for workers' body posture in the garment industry. This study corroborates previous research indicating that the REBA method effectively assesses work-related risks and hazards in the current design of sewing workstations for garment manufacturing. Furthermore, this study supports earlier findings that the REBA method can yield comprehensive results in evaluating work-related risks and hazards for garment workers, helping to determine whether immediate repairs are necessary based on ergonomic principles.

Table 4.3: A summary comparison of REBA score of the present study with the previous studies

Objectives	Methods	REBA score	Action level	References
To analyse the work activities of the finishing process.	REBA	5	Medium level of risk and requires necessary change.	Kusuma, (2020).
To identify the level of ergonomic risk.		5	Medium level of risk and requires necessary change.	Shah et al., (2016).
To assess work-related risks and hazards.		5*	Medium level of risk and requires necessary change.	Esmaeel, (Present study)
To assess WRMSDs.		8	High risk and requires necessary change soon.	Ahmad et al., (2021).
To improve workers' comfort and workplace safety by reducing WRMSDs.		8	High risk and requires necessary change soon.	Ahmed, (2018).
To analyze the work body posture of workers at the garments manufacturing.		11	Very high level of risk and requires necessary change now.	Wibowo & Mawadati, (2021).
To provide a summary of the REBA, in terms of validity.		11	Very high level of risk and requires necessary change now.	AI Madani & Dababneh, (2016).
To assess work-related MSDs.		12	Very high level of risk and requires necessary change now.	Beatrix, (2021).

*REBA score of the present study

4.2 Determining the Relevant Anthropometric Dimensions from Garments Workers

The results of 100 sewing workers' anthropometric data were obtained from garment workers (50% males and 50% females) at the sewing workstation, REAL, Eldoret, Kenya. The anthropometric data were analysed using one-way ANOVA and Minitab. See Appendix XI for the anthropometric data record. The results of this objective are described in the following sections:

4.2.1 Anthropometric Dimension of the Males and Females Workers at the Sewing Workstation

A summary of the descriptive statistics results for the recorded anthropometric data sets of male and female garment workers at the sewing workstation, REAL, Eldoret, Kenya. These statistics include the 5th, 50th, and 95th percentiles, mean, standard deviation (SD), minimum (min), and maximum (max) of the entire anthropometric data collected for garment-making workers. A summary of the descriptive statistics results for the recorded anthropometric data sets of male and female workers is shown in Table 4.4.

Table 4.4: A summary of descriptive statistics results of the recorded anthropometric data sets for male and female workers

Variable	**Male**								**Female**							
	Mean	SD	Min	Max	Percentiles			Unit	Mean	SD	Min	Max	Percentiles			Unit
					5th	50th	95th						5th	50th	95th	
Sitting height	82.98	2.48	79.50	89.10	79.80	82.25	87.20	Cm	79.22	3.68	70.80	94.30	73.50	79.20	86.50	Cm
Shoulder height	55.89	2.53	52.10	60.70	52.40	55.60	60.30		53.52	2.55	47.10	60.50	49.20	53.40	57.10	
Popliteal height	46.87	2.54	43.10	52.80	43.70	46.10	52.30		43.35	1.74	40.20	48.00	40.60	43.25	46.50	
Elbow height	17.34	3.04	12.80	24.40	13.30	17.55	22.30		17.53	3.05	11.20	27.50	13.20	17.50	22.40	
Buttock popliteal length	52.66	3.12	47.10	60.50	49.20	52.20	58.30		50.86	2.97	42.00	59.00	45.40	51.00	56.00	
Buttock knee length	62.69	3.44	57.10	71.40	59.00	62.15	69.10		60.72	2.91	54.10	67.70	56.10	60.50	65.40	
Thigh clearance	11.80	2.05	8.80	15.70	09.00	11.60	15.30		13.12	2.70	08.30	19.30	08.60	13.15	18.00	
Eye height sitting	71.56	2.25	67.30	75.70	67.90	71.50	75.50		67.59	2.54	59.80	74.00	63.00	68.00	71.30	
Knee height sitting	52.77	3.46	48.20	60.60	49.40	51.40	59.40		50.11	2.28	45.80	55.30	47.00	49.65	55.00	
Forearm fingertip length	47.93	2.61	42.48	53.41	43.85	47.70	52.86		45.04	2.16	37.99	50.32	41.78	45.24	48.89	
Hip breadth sitting	33.50	2.56	29.18	39.09	29.92	32.94	36.85		36.67	3.01	30.49	46.41	32.98	35.98	42.16	

4.2.2 One-Way Analysis of Variance (ANOVA) Results

The eleven anthropocentric parameters obtained from the workers (both males and females) were compared for variability using the one-way ANOVA analytical tool. Additionally, the following hypotheses were analysed and tested:

H_0: All samples means are significantly equal.

H_1: At least one mean is significantly different.

Significance level ($\alpha = 0.05$).

Rejection criterion:

Reject H_0 if the p-value is less than the significance level ($P < 0.05$).

Fail to reject H_0 if p-value is greater than the significance level ($P > 0.05$).

The ANOVA test results failed to reject the null hypothesis in the data sets ($P > 0.05$). This indicates that the means of the different samples are equal, demonstrating that there was no significant difference among the anthropometric data sets between male and female workers. These findings align with the study by Ezugwu et al., (2020), which reported no significant differences ($P > 0.05$) among the anthropometric data sets between genders for Nigerian workers at the sewing workstation. Table 4.5 presents the one-way ANOVA results.

Table 4.5: One-way ANOVA results

Variable	Source of variation	SS	df	MS	F	P-value	F-crit
Sitting height (erect)	Between workers (male and female)	258.3634	1	258.3634	21.88586	9.27E-06*	3.938111
Shoulder height sitting		99.36267	1	99.36267	15.3365	0.000166	3.938111
Popliteal height sitting		226.7844	1	226.7844	59.22882	1.12E-11*	3.938111
Elbow height sitting		0.768505	1	0.768505	0.082836	0.774098*	3.938111
Buttock popliteal length		58.96807	1	58.96807	6.520585	0.012205	3.938111
Buttock knee length		70.6427	1	70.6427	7.61407	0.006912	3.938111
Thigh clearance		31.7497	1	31.7497	4.832133	0.030288	3.938111
Eye height sitting		291.0086	1	291.0086	47.54426	5.28E-10*	3.938111
Knee height sitting		129.0887	1	129.0887	18.95459	3.29E-05*	3.938111
Forearm fingertip length		152.2521	1	152.2521	29.44268	4.16E-07*	3.938111
Hip breadth sitting		183.3858	1	183.3858	21.68026	1.01E-05*	3.938111

*No significant at P-value > 0.05

4.2.3 Anthropometric Dimension of the Workers at the Sewing Workstation

The analyses of the anthropometric data sets of the workers are presented in Table 4.6, including means, standard deviations, and the 5^{th}, 50^{th}, and 95^{th} percentiles, as well as the minimum and maximum dimensions. In anthropometry, the percentiles of various body dimensions are utilised to determine the redesign dimentions. For seat height, the 5^{th} percentile (lower percentile) of the population's popliteal height is typically recommended, ensuring that a larger portion of the population is accommodated, thus allowing shorter individuals to use the redesigned sewing workstation. The 5^{th} percentile of the buttock-popliteal length is considered for seat depth, shoulder height sitting for upper backrest height, and armrest height for lower backrest height. The 95^{th} percentile (higher percentile) of hip breadth sitting is generally suggested in the redesign of seat widths to accommodate as many individuals as possible, allowing taller persons to utilise the sewing workstation redesign. The data obtained from this study is beneficial for the sewing workstation redesign in garment manufacturing. With these characteristics, the study can establish and integrate an anthropometric database for an ergonomically innovative sewing workstation suitable for garment-making workers. Table 4.6 summarises the anthropometric measures based on the average of the collected data, which can be used in redesigning a sewing workstation for garment workers in Kenya.

Table 4.6: A summary of anthropometric dimensions for workers (n = 100 and all dimensions in cm).

Variable	Mean	SD	Min	Max	Percentiles		
					5th	50th	95th
Sitting height (erect)	80.12	3.78	70.80	94.30	74.00	80.05	87.05
Shoulder height sitting	54.08	2.72	47.10	60.70	49.50*	54.15	58.65
Popliteal height sitting	44.19	2.47	40.20	52.80	41.20*	43.85	48.65
Elbow height sitting	17.48	3.03	11.20	27.50	13.25*	17.50	22.35
Buttock popliteal length	51.29	3.09	42.00	60.50	46.20*	51.30	56.25
Buttock knee length	61.19	3.15	54.10	71.40	56.30	61.05	66.60
Thigh clearance	12.80	2.61	08.30	19.30	08.90	12.25	17.10
Eye height sitting	68.56	3.00	59.80	75.70	63.59	68.55	73.65
Knee height sitting	50.75	2.84	45.80	60.60	47.10	50.25	55.75
Forearm fingertip length	45.73	2.58	37.99	53.41	42.14	45.72*	50.02
Hip breadth sitting	35.91	3.19	29.18	46.41	31.16	35.54	41.55*

*Relevant anthropometric measures for the recommended sewing workstation (sewing chair and adjustable sewing machine table) redesign.

4.2.4 Proposed Dimensions of the Ergonomic Redesign of the Sewing Workstation

After analysing all eleven anthropometric measurements of the workers at REAL, Eldoret, Kenya, a final specification for the ergonomic sewing workstation redesign was proposed, aiming to accommodate the maximum number of workers in garment manufacturing. The recommended dimensions for the redesigned ergonomic sewing workstation, based on workers' anthropometric data, are as follows: seat height is 41.65 cm, seat depth is 46.20 cm, seat width is 47.78 cm, backrest width is 47.78 cm, backrest height (upper) above the seat is 49.50 cm, and backrest height (lower) above the seat is 13.25 cm. Similarly, research by Harrison et al., (2008) also designed an ergonomic sewing workstation based on workers' anthropometric data, establishing that the design of the workstation and the principles of ergonomics are effectively integrated into the sewing workstation redesign for garment manufacturing. The recommended dimensions for redesigning a workstation, along with their criteria for use in the sewing workstation at REAL, Eldoret, Kenya, are summarised and presented in Table 4.7.

Table 4.7: Proposed dimensions for a redesign for use in sewing workstations by garments workers at REAL, Eldoret, Kenya

S. No.	Seat feature	Anthropometric measure	Dimensions (cm)	Criteria/Determinant	References
1.	Seat height	Popliteal height sitting	41.65	5^{th} percentile of popliteal height + 0.45 cm shoe heel allowance	Ismaila et al., (2013).
2.	Seat depth	Buttock popliteal length	46.20	5^{th} percentile of buttock popliteal length	Mohamed et al, (2010).
3.	Seat width	Hip breadth sitting	47.78	95^{th} percentile of hip breadth + 15% allowance for clothing	Musa & Ismaila., (2014).
4.	Back rest width	Hip breadth sitting	47.78	As with seat width	Ismaila et al., (2013).
5.	Backrest height (Upper) above seat	Shoulder height sitting	49.50	5^{th} percentile of shoulder height	Mohamed et al., (2010).
6.	Backrest height (Lower) above seat	Elbow height sitting	13.25	5^{th} percentile of elbow height sitting	Ismaila et al., (2013).
7.	Arm rest height				
8.	Backrest angle	-	109^0	Literature review suggestions	Mohamed et al., (2010).
9.	Seat angle	-	110^0	From literature review	Igbokwe et al., (2019).
10.	Sewing table height	Functional elbow height	60.73	Seat height + functional elbow height + shoe heel allowance	Ismaila et al., (2013).
11.	Sewing table depth	Forearm fingertip length	45.72	50^{th} percentile of forearm fingertip length	
12.	Sewing table width	Hip breadth	54.01	95^{th} percentile of hip breadth + 15% allowance for clothing + 15% allowance as clearance	
13.	Sewing table angle to horizontal	Table with horizontal	15^0	Literature review suggestions	Ahmed, (2018).

4.2.5 Dimensions of the Existing Sewing Workstation

The essential dimensions of the existing sewing workstation furniture for workers at the REAL factory have been gathered to identify mismatches between the workstation dimensions and the workers' body measurements. The summarised measurements are displayed in Table 4.8.

Table 4.8: Dimensions of the existing sewing workstation furniture for workers

Abbreviations	Dimensions of the existing sewing workstation		Unit
SH	Seat height	40.00	Cm
SD	Seat depth	38.90	
SW	Seat width	37.20	
TH	Table height	75.80	

4.2.6 Comparison of the Existing and Proposed Sewing Workstation Dimensions with Worker's Body Measurements

The sewing workstation dimensions and the corresponding worker body measurements are calculated and compared using equations (3.9), (3.10), (3.11), and (3.12) as outlined in the methodology section. The summarised mismatch between the existing and proposed sewing workstation dimensions and the worker body dimensions are presented in Table 4.9 and Figure 4.4. The results indicate a significant mismatch between the existing sewing workstation dimensions and the worker's anthropometric measurements. In this study, the mismatches for the existing design are found in seat height at 63%, seat depth at 81%, seat width at 79%, and sewing table height at 98%. These findings are consistent with a previous study by Ahmed, (2018), which reported mismatches in seat height at 64.86%, seat depth at 100%, seat width at 81%, and sewing table height at 100%. Additionally, this present study also, aligns with earlier research by M. Ali, et al., (2014), which found considerable mismatches between body dimensions and sewing furniture dimensions, with seat height at 79%, seat depth at 94%, seat width at 36%, and sewing table height at 79%.

The results comparing existing and proposed sewing workstation dimensions with the worker's anthropometric measurements were analysed before and after the integration of anthropometric data. It was found that the seat height (SH) against to popliteal height (PH) reduced from 63% to 33%, seat depth (SD) against to buttock-popliteal length (BP) reduced from 81% to 21%, seat width (SW) against to hip breadth (HB) reduced from 79% to 67%, and table height (TH) against to elbow height (EH) also reduced from 98% to 55%. The findings of the present study indicate that the ergonomically redesigned workstation, based on workers' anthropometric data, can significantly reduce the mismatch between sewing workstation dimensions and the worker's body dimensions. Table 4.9 and Figure 4.4 illustrate the summary of the mismatch between sewing workstation dimensions and worker's body dimensions.

Table 4.9: A summary of the mismatch between sewing workstation dimensions and worker's body dimensions

Dimensions	**Existing design**	**Proposed redesign**
	Percentage of mismatch	Percentage of mismatch
PH and SH	63%	33%
BPL and SD	81%	21%
HB and SW	79%	67%
TH and EH	98%	55%

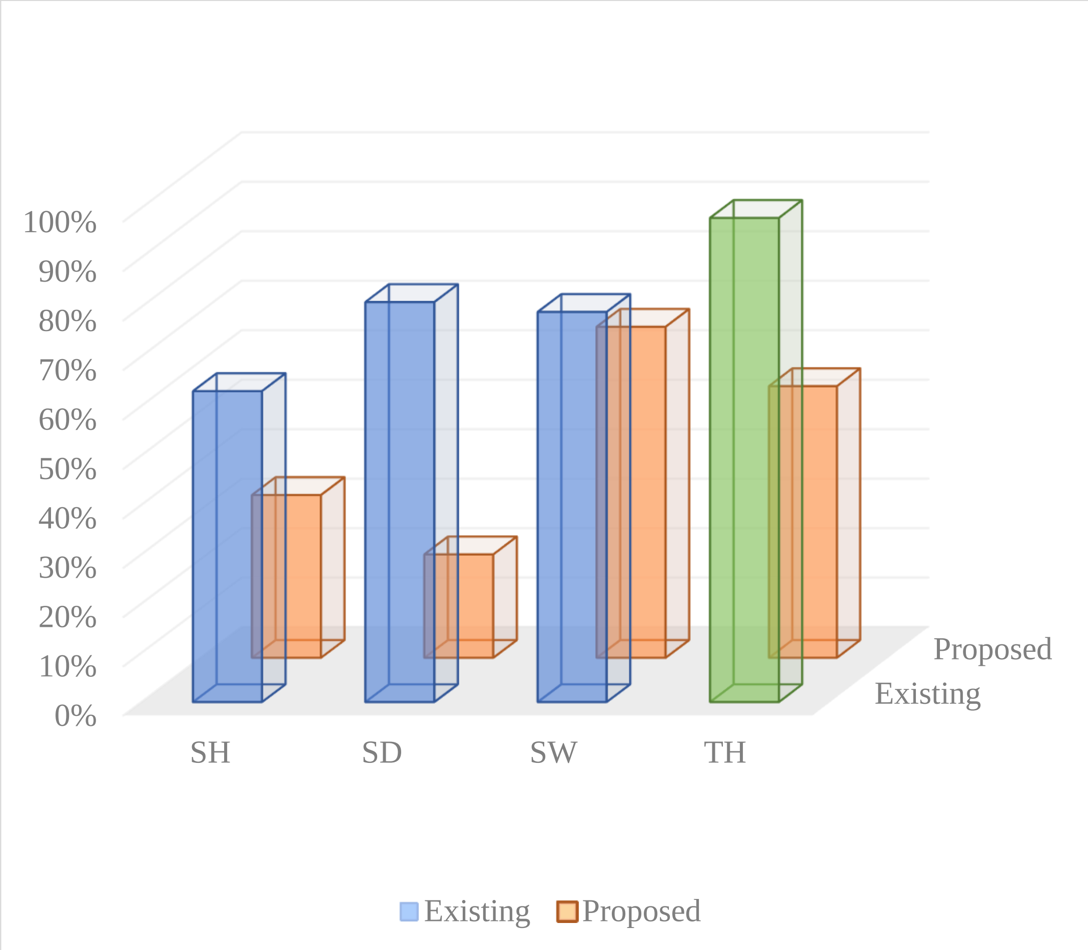


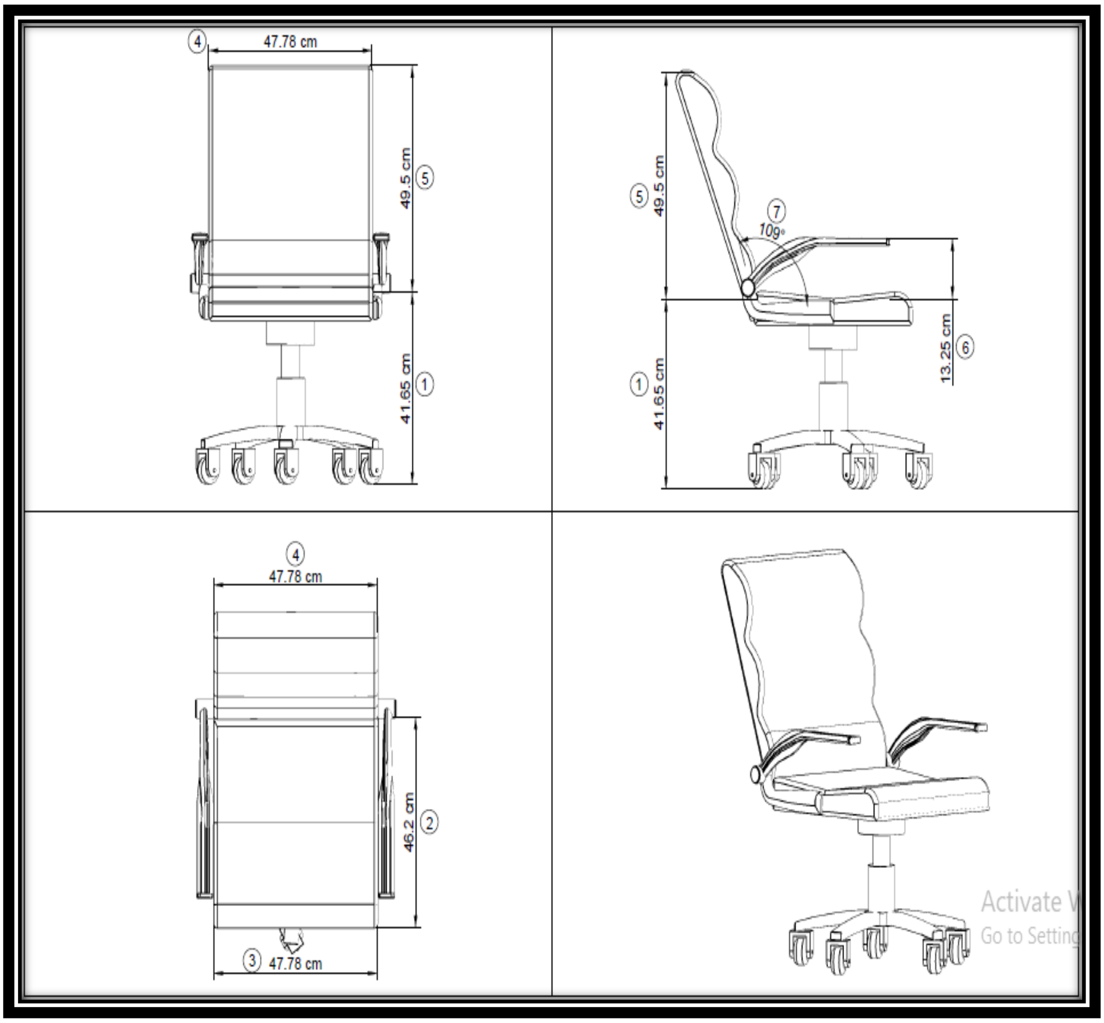
Figure 4.4: A summary of the mismatch between sewing workstation dimensions and worker's body dimensions

4.3 Redesigning a workstation for garments workers

In the case of the ergonomic redesign of the sewing operation workstation, it is essential to achieve a balance between the workstation's dimensions and the operator's anthropometric measurements to reflect the man-machine relationship. The results of the workstation redesign for garment-making workers at sewing operations are discussed in detail below:

4.3.1 Sketches and Complete Model of the Proposed Redesigns

The redesign process commenced with concept creation rooted in a user-centered design that prioritised safety and health to mitigate ergonomic risks. This is crucial, as user-centered design is a fundamental technique for sewing product redesign that will be integrated with anthropometric data and user recommendations. The redesign approach must accommodate 95% of the workers, and effective conceptual design enables users to anticipate the consequences of their actions. This implies that a well-conceived redesign of the workstation will encourage or inspire workers to use it comfortably and confidently. Following the analysis of the recorded data, as illustrated in the previous Tables 4.6 and 4.7, the proposed ergonomically innovative sewing workstation (including the adjustable sewing chair and adjustable sewing machine table) was developed using SolidWorks, as depicted in Figures 4.5, 4.6, 4.7, and 4.8 respectively.



Keys:

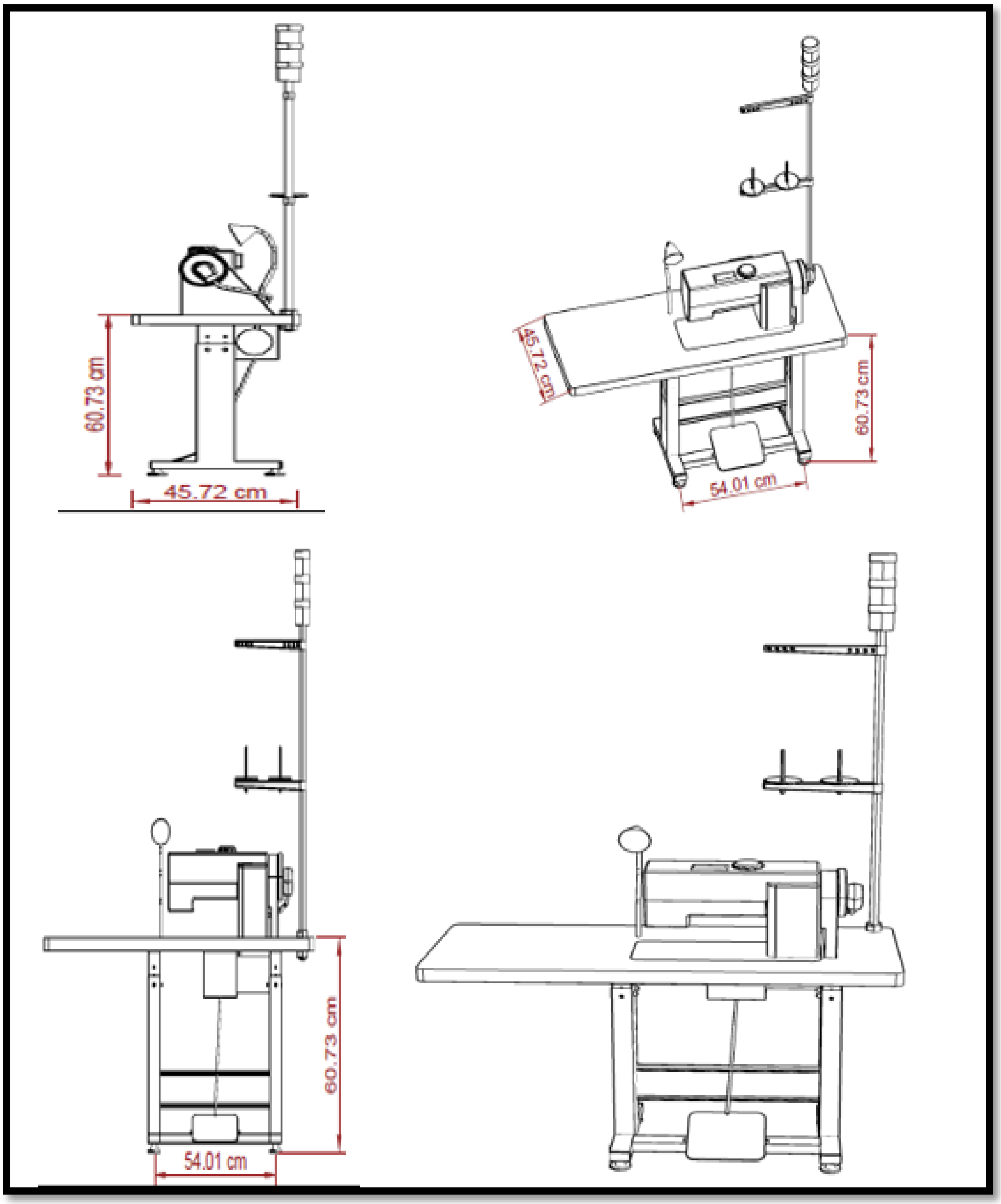
No.	Seat feature	Dimensions (cm)
1	Seat height	41.65
2	Seat depth	46.20
3	Seat width	47.78
4	Back rest width	47.78
5	Backrest height (Upper) above seat	49.50
6	Arm rest height	13.25
7	Backrest angle	109^0

Figure 4.5: Sketches of the proposed adjustable workers' sewing chair workstation

Keys:

No.	Seat feature	Dimensions (cm)
1	Seat height	41.65
2	Seat depth	46.20
3	Seat width	47.78
4	Back rest width	47.78
5	Backrest height (Upper) above seat	49.50
6	Arm rest height	13.25
7	Backrest angle	109^0

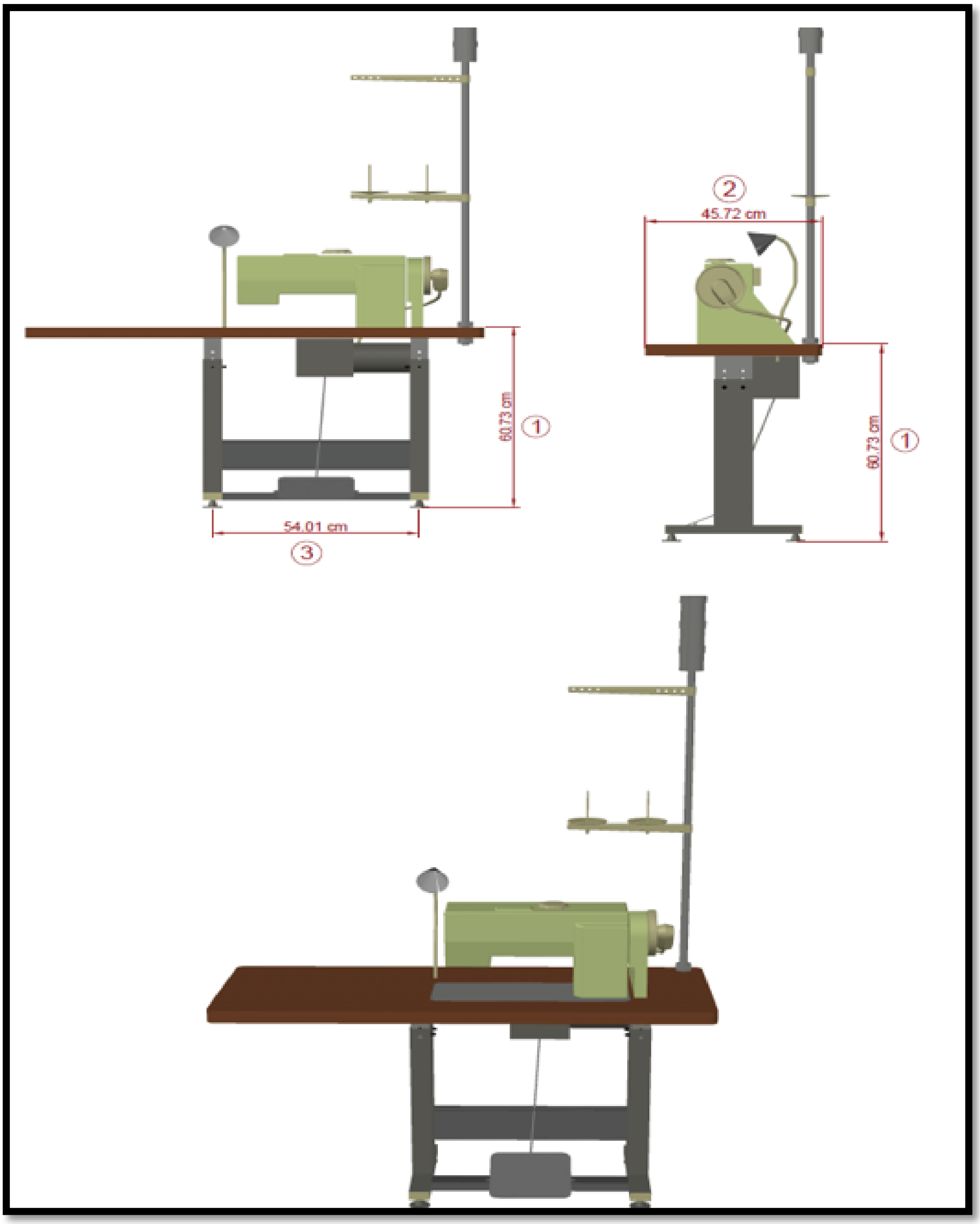
Figure 4.6: Complete model of the proposed adjustable workers' sewing chair



Keys:

Table feature	Dimensions (cm)
Sewing table height	60.73
Sewing table depth	45.72
Sewing table width	54.01

Figure 4.7: Sketches of the proposed workers' adjustable sewing machine table



Keys:

No.	Table feature	Dimensions (cm)
1	Sewing table height	60.73
2	Sewing table depth	45.72
3	Sewing table width	54.01

Figure 4.8: Complete model of the proposed workers' adjustable sewing machine table

4.3.2 Workers' Requirements Survey Results

The sample of 100 respondents (50% male and 50% female) was randomly selected from the workers at REAL, Eldoret, Kenya. Additionally, a questionnaire was chosen as the most suitable method, which was pre-tested to ensure its reliability and validity. The questionnaire data was analysed list-wise using Minitab, and the results are presented in the following details:

4.3.2.1 Arranging the Importance of the Needs

The ranking of the importance of the needs was conducted after all the questionnaire data was analysed using Minitab. Refer to the questionnaire form in Appendix XII. Table 4.10 presents the importance of the needs of the sewing workstation based on the workers' requirements survey results. See Appendix XIII for the complete data record. This ranking was performed on a scale from 1 to 5 (1 being the lowest and 5 the highest). The results were analysed to obtain an average, and only a summary of these results is displayed.

Table 4.10: Importance of the needs of the sewing workstation

No.	Functional requirements	Importance
A.	Adjustable height and back sewing chair	4
B.	Adjustable height sewing chair	3
C.	Arrow and craft sewing chair	4
D.	Camping sewing chair	3
E.	Arm sewing chair	3
F.	Armless sewing chair	5
G.	Sindre sewing chair	2
H.	Folding sewing chair	2

4.3.2.2 Arranging the Importance of the Factors

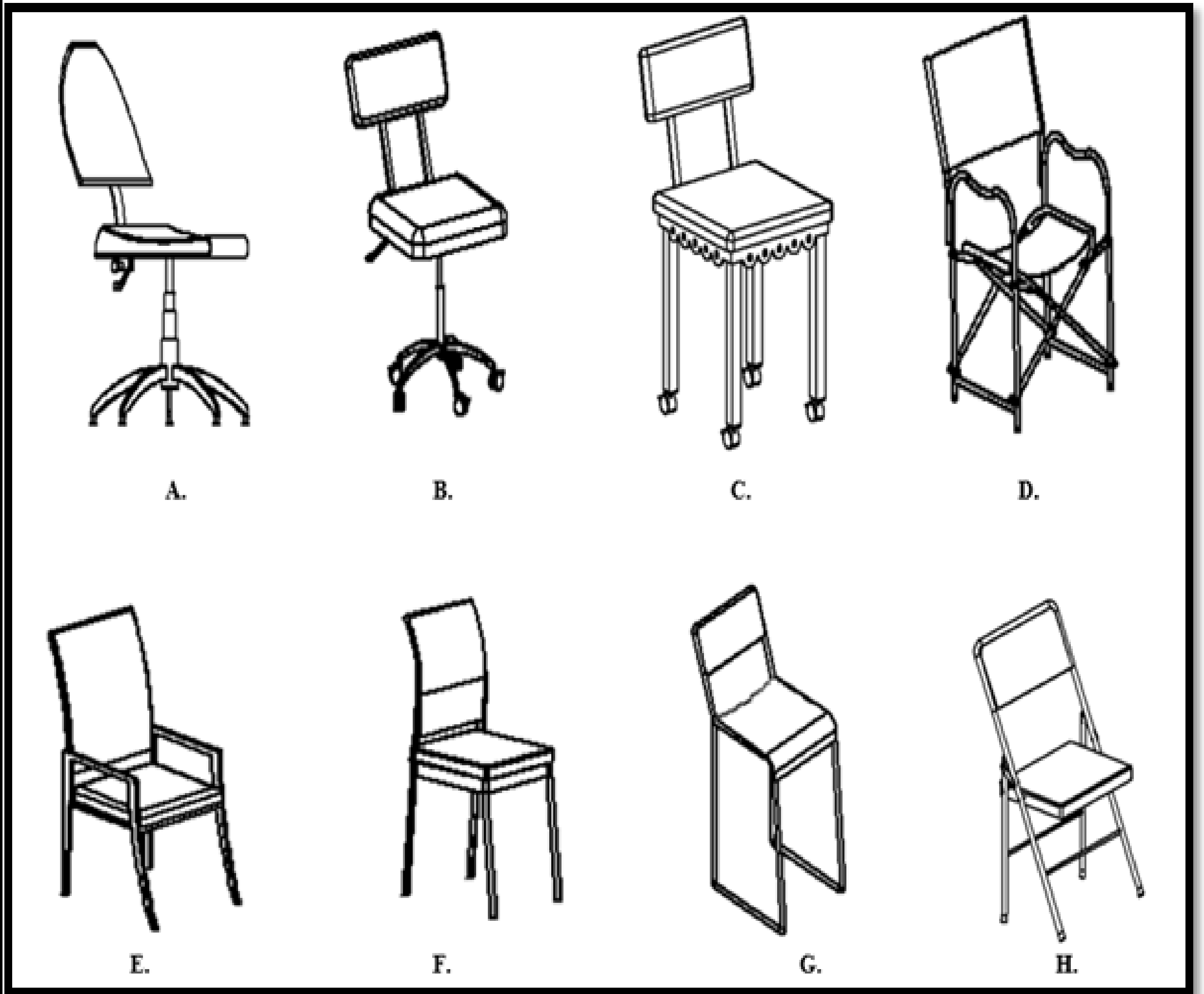
The factors of importance were organised through a questionnaire and analysed using Minitab software. Table 4.11 displays the significance of the factors in the ergonomic sewing chairs redesign based on the workers' requirements survey results. This ranking was conducted on a scale of 1 to 5 (where 1 is the lowest and 5 is the highest), which was converted into weights, and the results are presented only as a summary.

Table 4.11: Importance of the factors of the sewing workstation

No.	Selection factors	Weight
1.	Ergonomics and safety	9%
2.	Ease of use	7%
3.	Ease of manufacture	9%
4.	Durability	8%
5.	Aesthetic	7%
6.	Reliability	7%
7.	Maintainability	9%
8.	Social appeal	6%
9.	Environmental soundness	9%
10.	Economic value	8%
11.	Utility and function	6%
12.	Life cycle cost	8%
13.	Availability	7%

4.3.3 Concepts Generation

From the review of the previous designs of the sewing chairs and the ideas, eight concepts for the current ergonomic sewing chair workstation were generated after analysing all the workers' needs. At this stage, eight distinct concepts of the ergonomic sewing chair workstation were developed based on the workers' requirements, with each concept featuring its own unique functionalities. These eight conceptual sewing chairs were: A. Adjustable height and back sewing chair, B. Adjustable height sewing chair, C. Arrow and craft sewing chair, D. Camping sewing chair, E. Arm sewing chair, F. Armless sewing chair, G. Sindre sewing chair, and H. Folding sewing chair. These eight conceptual sewing chairs were created using SolidWorks software and are presented in Figures 4.9 (A), (B), (C), (D), (E), (F), (G), and (H).



Keys:

A. Adjustable height and back sewing chair

B. Adjustable height sewing chair

C. Arrow and Craft sewing chair

D. Camping sewing chair

E. Arm sewing chair

F. Armless sewing chair

G. Sindre sewing chair

H. Folding sewing chair

Figure 4.9: Eight concept redesign of the sewing chairs

4.3.4 Concept Scoring Matrix

After generating all eight redesign concepts for the sewing chairs workstation, the next step was to select the best sewing chair redesign using the Concept Scoring Matrix (CSM) method to simulate, optimise, and fabricate it as well. The purpose of the CSM is to identify the optimal conceptual redesign of the proposed ergonomic sewing workstation among the eight redesigns (A, B, C, D, E, F, G, and H) as illustrated in Figure 4.9 above. In this process, all selection criteria are assigned specific weights in percentage, based on the results from the workers' requirements survey. These weights are distributed among the selection criteria, and the total of all weights must equal 100, as shown in Table 4.12. After distributing the weights among the 13 criteria, the next step is to rate the redesign concepts, with ratings assigned on a scale of 1 to 5 (1 being the lowest and 5 the highest). Each weighted score for the selection criteria is calculated by multiplying the rating by the specific weight, which is then summed to obtain the total weighted score. The results from the CSM are presented in Table 4.12, where it is noted that concept (F) was selected with the highest net score of 5 and was used for simulation, optimisation, and fabrication as outlined in the research objectives.

Table 4.12: Display of the Concept Scoring Matrix (CSM)

Selection criteria	**Weight**	**Conceptual redesigns**															
		A		**B**		**C**		**D**		**E**		**F**		**G**		**H**	
		Rating	Weighting score	Rating	Weighting score	Rating	Weighting score	Rating	Weighting score	Rating	Weighting score	Rating	Weighting score	Rating	Weighting score	Rating	Weighting score
Ergonomics and safety	9%	4	0.36	3	0.27	4	0.36	3	0.27	3	0.27	5	0.45	2	0.18	2	0.18
Ease of use	7%	4	0.28	3	0.21	4	0.28	3	0.21	3	0.21	5	0.35	2	0.14	2	0.14
Ease of manufacture	9%	4	0.36	3	0.27	4	0.36	3	0.27	3	0.27	5	0.45	2	0.18	2	0.18
Durability	8%	4	0.32	3	0.24	4	0.32	3	0.24	3	0.24	5	0.40	2	0.16	2	0.16
Aesthetic	7%	4	0.28	3	0.21	4	0.28	3	0.21	3	0.21	5	0.35	2	0.14	2	0.14
Reliability	7%	4	0.28	3	0.21	4	0.28	3	0.21	3	0.21	5	0.35	2	0.14	2	0.14
Maintainability	9%	4	0.36	3	0.27	4	0.36	3	0.27	3	0.27	5	0.45	2	0.18	2	0.18
Social appeal	6%	4	0.24	3	0.18	4	0.24	3	0.18	3	0.18	5	0.30	2	0.12	2	0.12
Environmental soundness	9%	4	0.36	3	0.27	4	0.36	3	0.27	3	0.27	5	0.45	2	0.18	2	0.18
Economic value	8%	4	0.32	3	0.24	4	0.32	3	0.24	3	0.24	5	0.40	2	0.16	2	0.16
Utility and function	6%	4	0.24	3	0.18	4	0.24	3	0.18	3	0.18	5	0.30	2	0.12	2	0.12
Life cycle cost	8%	4	0.32	3	0.24	4	0.32	3	0.24	3	0.24	5	0.40	2	0.16	2	0.16
Availability	7%	4	0.28	3	0.21	4	0.28	3	0.21	3	0.21	5	0.35	2	0.14	2	0.14
Net score		4		3		4		3		3		5		2		2	
Rank		Second		Third		Second		Third		Third		First		Fourth		Fourth	
Continue?		No		No		No		No		No		Develop		No		No	

4.3.5 Sketches of the Selected Proposed Redesign of the Sewing chair Workstations

This research utilised a 3D model of the redesigned sewing chair, beginning with the creation of sketches and subsequently integrating them into a complete assembly to achieve the final 3D model. The sketches of the selected ergonomic concept sewing chair workstations were reimagined according to ergonomic principles. Utilising anthropometric data, the ergonomic sewing chair was restructured for garment-making workers at REAL in Eldoret, Kenya, using SolidWorks. The sketches of the ergonomically redesigned sewing chair workstation are presented in Figures 4.10 and 4.11, respectively.

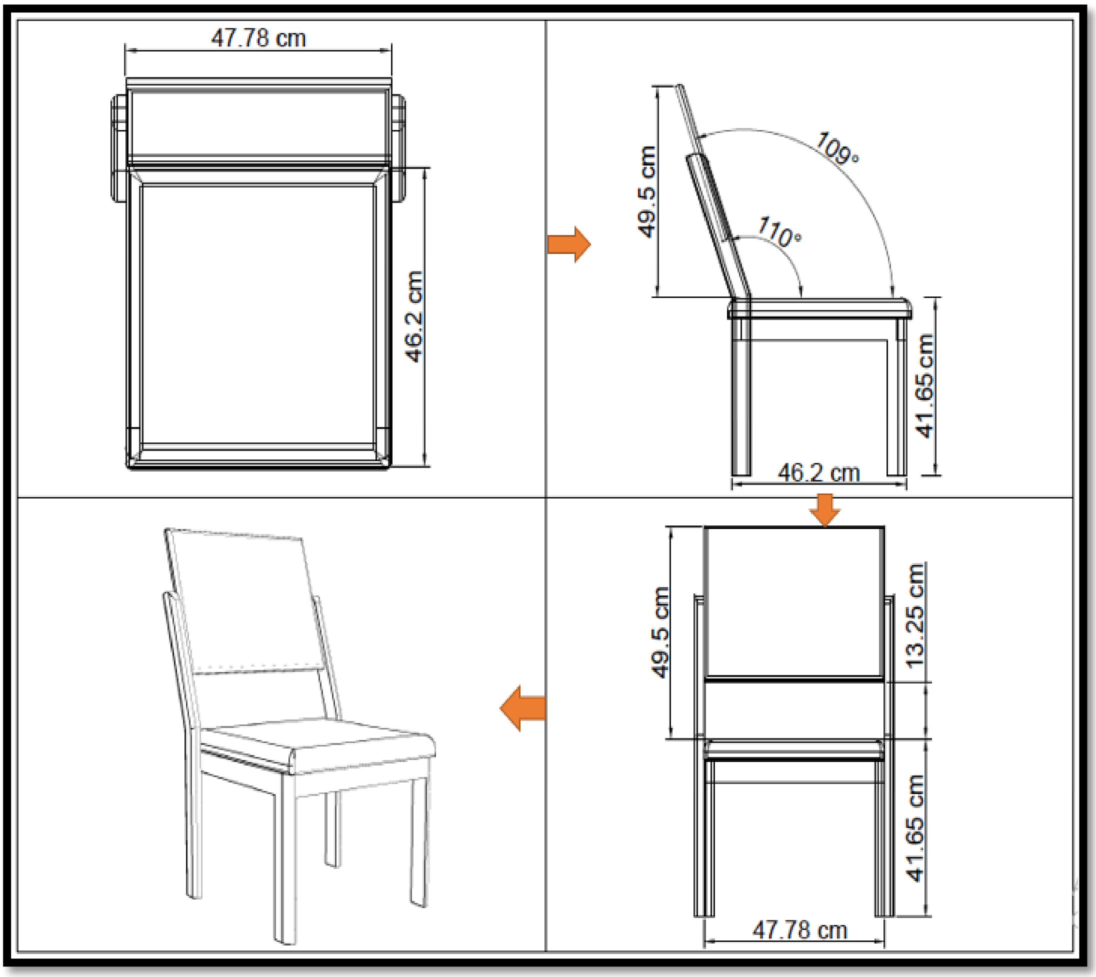
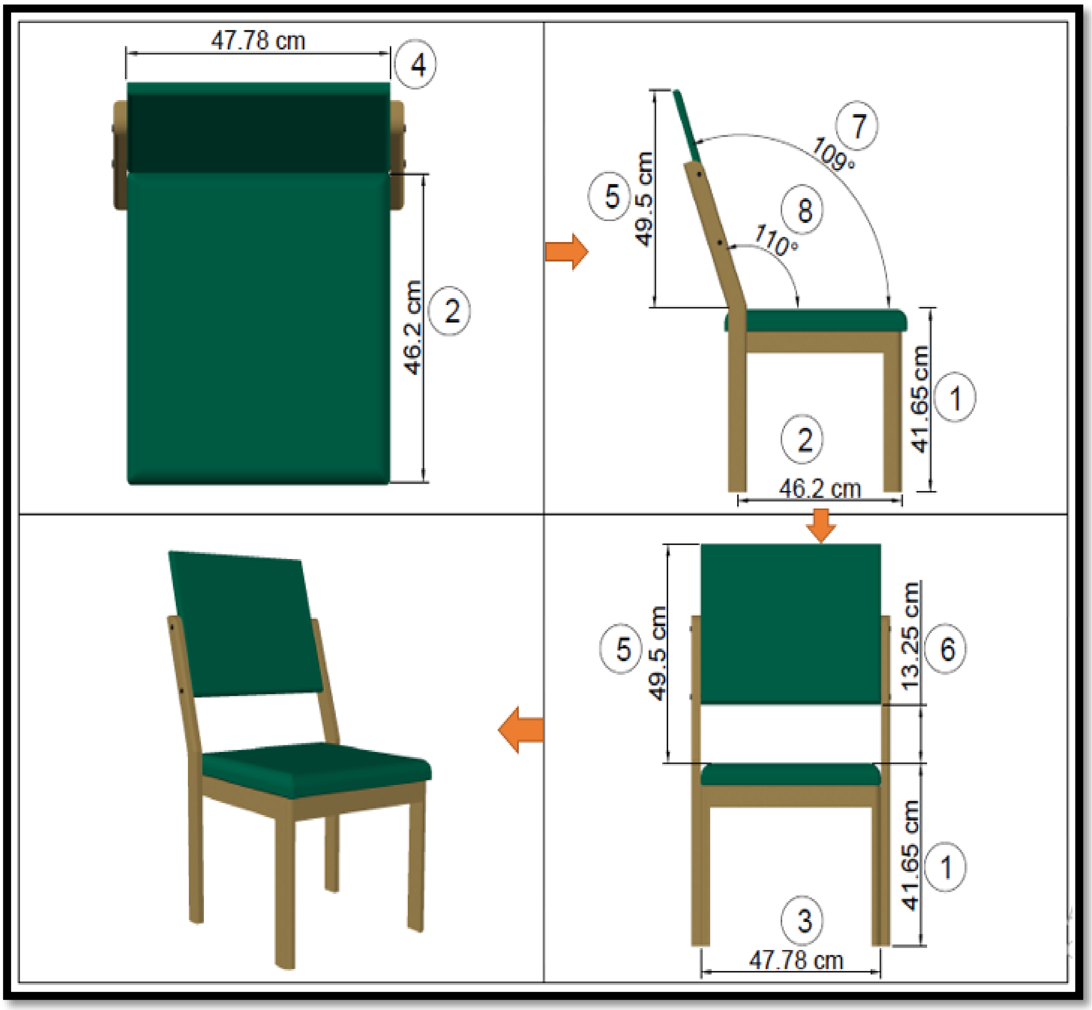


Figure 4.10: Sketches of the selected proposed workers' sewing chair workstation



Keys:

No.	Seat feature	Dimensions (cm)
1	Seat height.	41.65
2	Seat depth.	46.20
3	Seat width.	47.78
4	Back rest width.	47.78
5	Backrest height (Upper) above seat.	49.50
6	Backrest height (Lower) above seat.	13.25
7	Backrest angle.	109^0
8	Seat angle.	110^0

Figure 4.11: Sketches of the proposed workers' sewing chair workstation selected

4.3.6 Completing Model of the Selected Proposed Redesign of the Sewing chair

The model of the concept redesign of the ergonomic sewing chair was completed using SolidWorks, based on the average anthropometric data mentioned earlier in Table 4.7. The frame and the complete model of the ergonomic concept redesign of the selected sewing chair workstation are illustrated in Figures 4.12 and 4.13, respectively.

Figure 4.12: Complete frame of the proposed workers' sewing chair selected

Figure 4.13: Complete model of the proposed workers' sewing chair selected

4.3.7 Completing Assembly of the Ergonomically Sewing Workstation

After modeling in SolidWorks, the models were imported into CATIA V5 ergonomics design and analysis 3D CAD software to complete the assembly of the models (selected sewing chair + adjustable sewing machine table + DHM for RULA analysis, as shown in Figure 4.14).

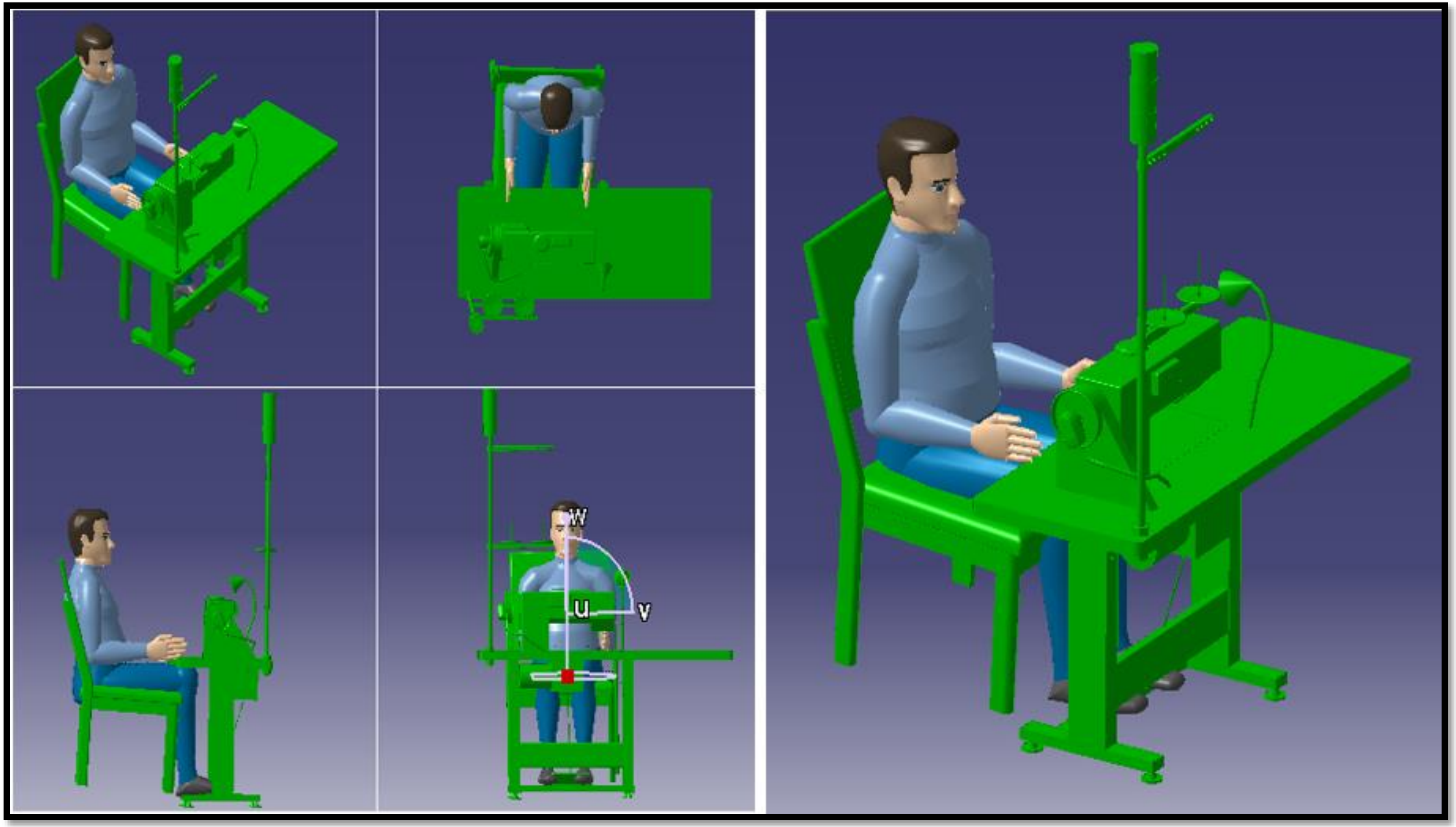


Figure 4.14: Complete assembly of the models (selected sewing chair + adjustable sewing machine table + manikin) done by 3D CATIA

4.4 Simulating the Redesign of Workstations for Garment Workers

The results of the objective simulation regarding the redesign of workstations for garment-making workers in sewing operations have been achieved. RULA assessments were conducted on the sitting posture of the HDM, while FEA analyses were performed on the model of the selected sewing chair. These results are discussed in the following section:

4.4.1 Simulation Results of the Rapid Upper Limb Assessment (RULA) Analysis

The findings from the ergonomic analysis conducted on the sitting posture of the HDM are discussed in the following details:

4.4.1.1 The Evaluation Results of the Upper Limb Analysis

The assembly of the sewing workstation was assessed using a HDM representing the 50^{th} percentile of workers. The RULA analysis was conducted in a sitting position while a worker performed a task (sewing) in the sewing workstation environment. The RULA analysis method evaluates based on a score and colour, which are interrelated. The colours are green, yellow, orange, and red. Green indicates that the body posture is good and acceptable, while red signifies that the body posture is poor and requires immediate changes. The RULA analysis combines postural evaluations of different muscle groups characterised as: muscle group A (comprising the upper arm, lower arm, and wrist) and muscle group B (comprising the neck, trunk, and leg). The total score was calculated based on the combinations of both muscle groups. The evaluation results of upper limb analysis for the sitting posture of the HDM, based on anthropometric data, fell within the acceptable score range. The final RULA score of 1 indicated a negligible risk of MSDs, and thus the proposed redesign of the sewing workstation is deemed acceptable, as shown in Table 4.13.

Table 4.13: The evaluation analysis results of the upper limb

Place	Scores and colours		Recommendation
Upper arm	1		The evaluation analysis results of upper limb analysis for the sitting body posture of the HDM, based on the anthropometric data, were within the acceptable range. The final RULA score of 1 indicated a negligible risk of MSDs. Consequently, the redesign is deemed acceptable, and the dimensions of the proposed sewing workstation are finalised.
Forearm	1		
Wrist	1		
Wrist twist	1		
Posture A	1		
Muscle	0		
Force/load	0		
Wrist and arm	1		
neck	1		
Trunk	1		
Legs	1		
Posture B	1		
Neck, trunk and leg	1		
Final/total score	1		

4.4.1.2 Simulation Results of the RULA Ergonomic Analysis

The simulation results of the RULA ergonomic analysis were conducted on the complete assembly of the models (selected sewing chair + adjustable sewing machine table + manikin) using 3D CATIA V software. Consequently, the analysis of the sitting body posture of the HDM for the proposed ergonomic model yielded a final RULA score of 1, indicating that the ergonomic risk for MSDs was negligible. Thus, this study contributes to the comfort of workers at the workstation. Figure 4.15 illustrates the simulation results of the RULA ergonomic analysis for the complete assembly of the models at the sewing workstation.

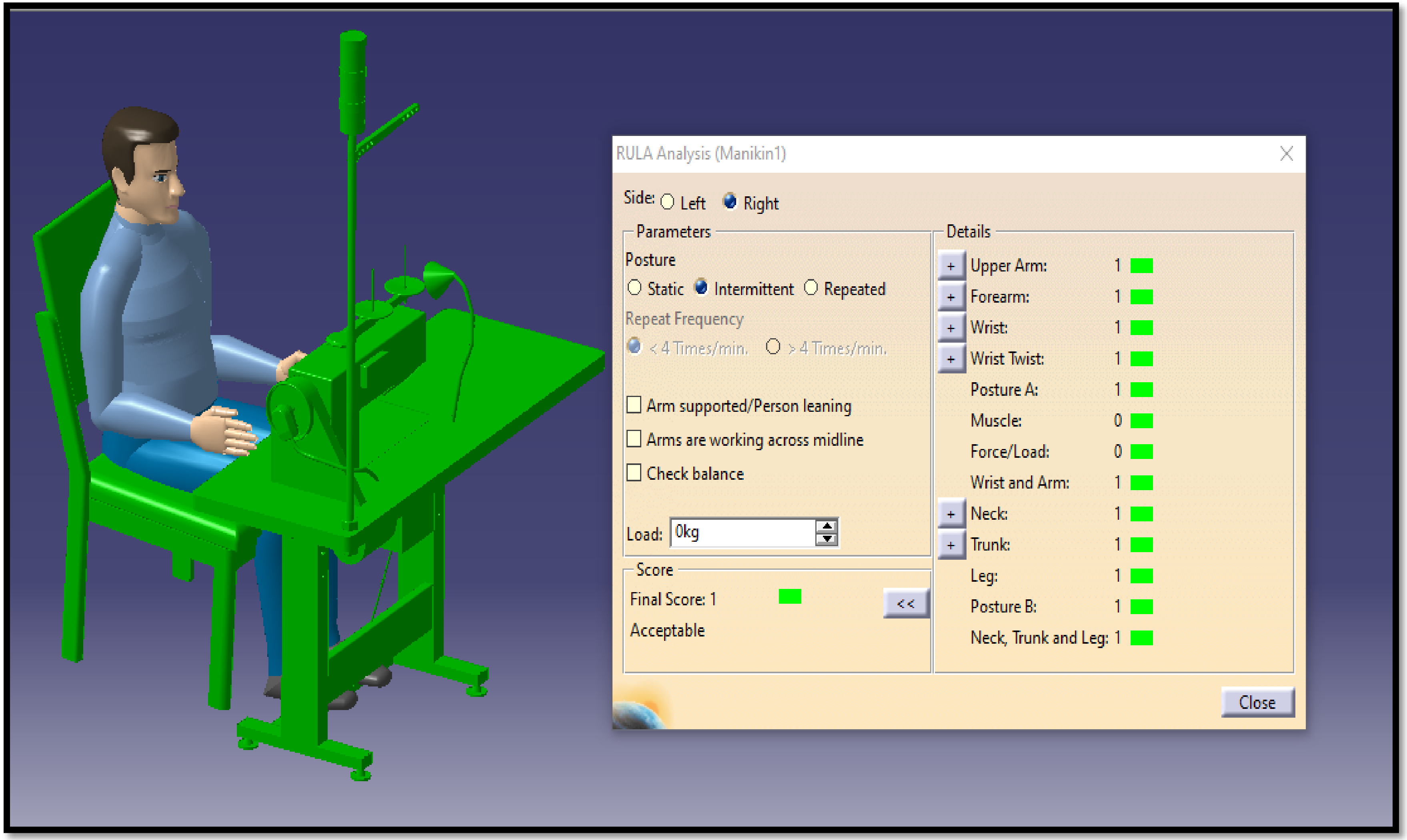


Figure 4.15: Simulation results of the RULA ergonomic analysis for HDM (manikin)

4.4.1.3 Comparison of RULA results of this study with the previous studies

The comparison of the RULA results from this study with those of previous analyses of HDM at the sewing workstation is presented in Table 4.14. Previous studies by Upasana & Vinay, (2017) on the work body posture in the sewing workstation and Öztürk & Esin, (2011) on ergonomic risk factors among female sewing machine operators found a final RULA score of 7, indicating a high level of risk that requires immediate changes. Previous rsearch by Saguyod et al., (2021) on ergonomic workstation design for apparel manufacturing workers and Shah et al., (2016) on awkward body postures in the garment manufacturing industry confirmed a final RULA score of 5, which signifies a medium level of risk that necessitates prompt changes. This study aligns with previous findings that indicate a final RULA score of 1 can yield maximum results in simulating an HDM in the proposed redesign of an ergonomically innovative sewing workstation for garment manufacturing. Furthermore, this study concurs with earlier research by Saguyod et al., (2021) and Shah et al., (2016), which asserts that RULA score results provide a comprehensive assessment in simulating an HDM to determine the acceptability of the sewing workstation redesign based on ergonomic principles.

Table 4.14: Comparison of RULA ergonomic analysis results of this present study with the previous studies

Titles of the Studies	Final RULA score	Risk Level	Recommendation	References
Work Posture Assessment of Tailors By RULA and REBA Analysis.	7	High	Investigation and changes required immediately	Upasana & Vinay, (2017)
Investigation of Musculoskeletal Symptoms and Ergonomic risk Factors among Female Sewing Machine Operators in Turkey.	7			Öztürk & Esin, 2011)
Working Conditions of Iranian Hand-Sewn shoe Workers and Associations with Musculoskeletal Symptoms.	6	Medium	Investigation and changes required soon	Dianat & Salimi, (2014)
Analysis of Working Posture on Musculoskeletal Disorders of Vocational Garment Student's in Garment Assembly Operations Practice.	5			Aribowo et al., (2020)
An Ergonomic Workstation Design for Apparel Manufacturing Workers in the Philippines.	5			Saguyod et al., (2021)
Ergonomic Risk Factors for Workers in Garments Manufacturing: A Case Study from Pakistan.	5			Shah et al., (2016)
Prevalence of Musculoskeletal Problems and Awkward Posture in a Pakistani Garments Manufacturing Industry.	5			
An Ergonomic Analysis of the Seat-Sewing.	4	Low	Further investigation and changes may be needed	Rittel, (2010)
Integration of Anthropometric Data in the Ergonomic Design of Sewing Workstation for Garments Manufacturing. Case Study At REAL, Eldoret, Kenya.	1*	Negligible	Acceptable	Present study

*RULA score of the present study

4.4.2 Simulation Results of FEA Static Analysis for the Selected Sewing Chair

A FEA static simulation study was conducted on the selected sewing chair model with a deformation scale of 30,050.2 to verify the model's capability to support the weight of the human body. An external force of 800 N (80 kg) was applied to the upper side of the sewing chair, while a force of 150 N (15 kg) was applied to the backrest. The FEA static test utilised aluminum alloy 1060 with the following properties: elastic modulus: 69,000 MPa; yield strength: 27.57 MPa; tensile strength: 68.93 MPa; specific heat: 900 J/(kg·K); Poisson's ratio: 0.33; mass density: 2,700 kg/m^3; thermal conductivity: 200 W/(m·K); and shear modulus: 27,000 MPa, to assess the chair's ability to support human weight. The complete report of the FEA static simulation results can be found in Appendix XIV. Additionally, the findings of the FEA static simulation studies are discussed in the following details:

4.4.2.1 Results of Stress Analysis of the Selected Sewing Chair Model

The stress analysis results for the selected sewing chair are presented in Figure 4.16 and Table 4.15, detailing the maximum and minimum stress values for the model acting on the seat and backrest. The maximum stress at the seat is 7.175E – 01 MPa, occurring at node 67581, while the minimum stress is 1.414E – 05 MPa, at node 48336. The maximum stress value for the model does not exceed the yield strength of the selected material, which is 2.757E + 01 MPa, remaining below the assigned safety level. Therefore, the model part will not break or fail under applied external loads.

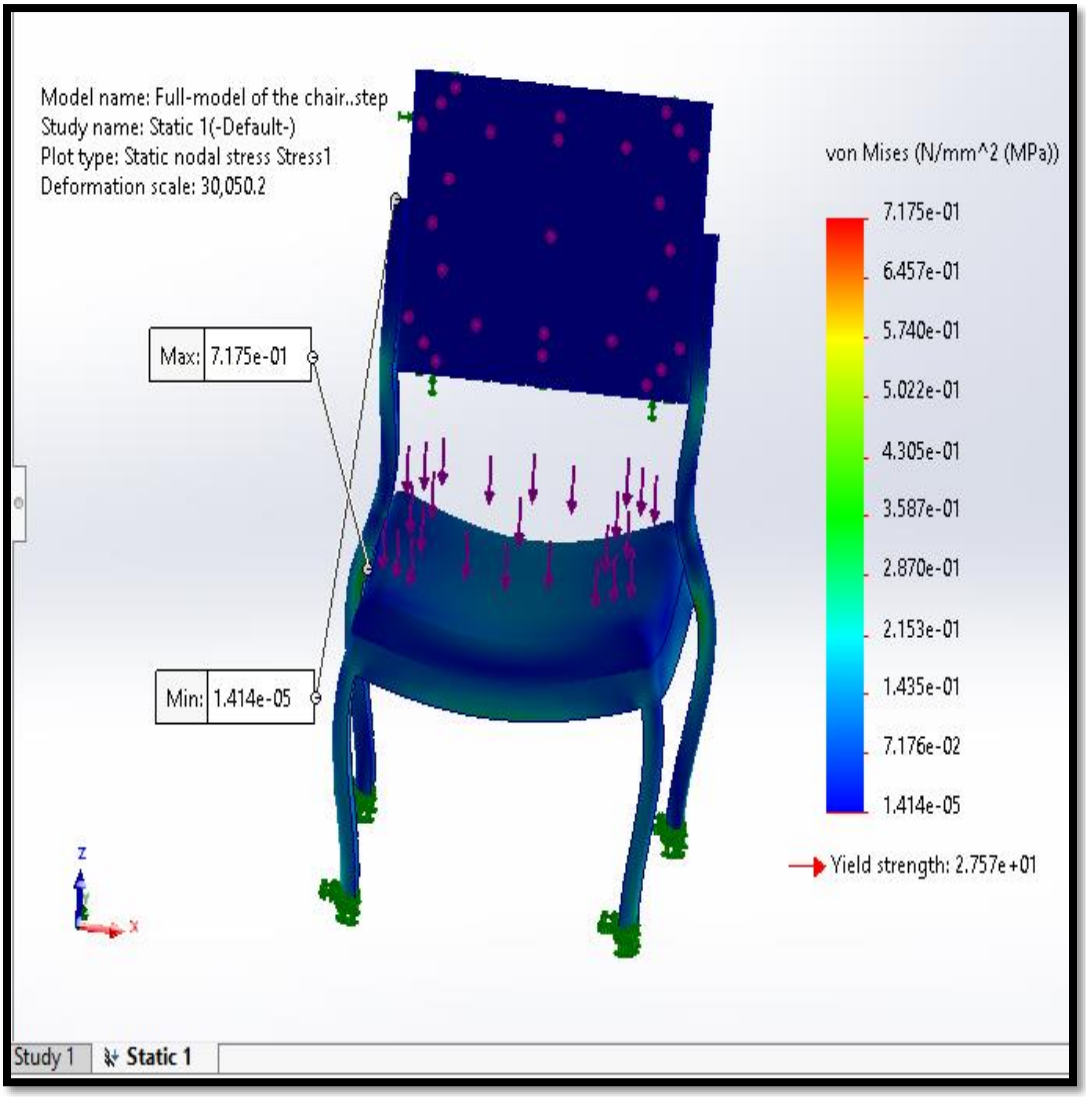


Figure 4.16: Results of stress analysis of the selected sewing chair model

Table 4.15: Results of stress analysis of the selected sewing chair model

Linear static analysis	**Value/Units**
Yield strength for the selected material	2.757E + 01 MPa
Max stress of the sewing chair model	7.175E – 01 MPa Node: 67581
Min stress of the sewing chair model	1.414E – 05 MPa Node: 48336

4.4.2.2 Results of Displacement Analysis of the Selected Sewing Chair Model

The displacement analysis results for the selected sewing chair model are presented in Figure 4.17 and Table 4.16, detailing the maximum and minimum displacement values for the model affecting the seat and backrest. The maximum displacement at the seat is 3.209E – 03 mm, occurring at node 26013, while the minimum displacement is 1.000E – 30 mm, at node 36303. The model's maximum deformation is quite small, measuring 0.03209 mm, which is below the assigned safety threshold. Therefore, the maximum displacement was observed when the model was subjected to the specified loads, which was barely noticeable; thus, it was determined that the part is acceptable for operation under those conditions.

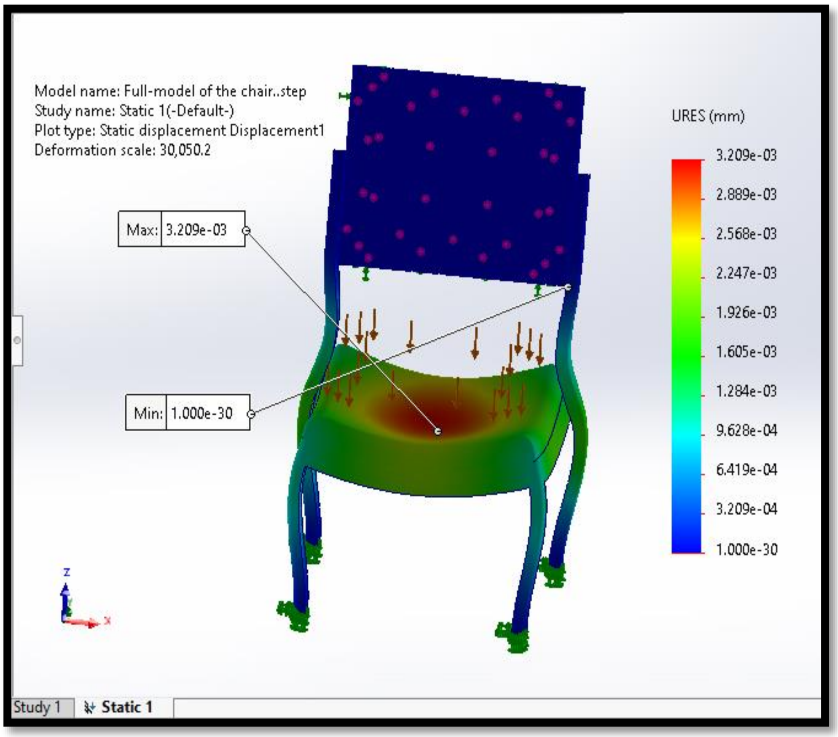


Figure 4.17: Results of displacement analysis of the selected sewing chair model

Table 4.16: Results of displacement analysis of the selected sewing chair model

Linear static analysis	Value/Units
Maximum deformation for model	0.03209 mm
Max displacement of the sewing chair model	3.209E – 03 mm Node: 26013
Min displacement of the sewing chair model	1.000E – 30 mm Node: 36303

4.4.2.3 Results of Strain Analysis for the Selected Sewing Chair Model

The strain analysis results for the chosen sewing chair model are presented in Figure 4.18 and Table 4.17. The maximum strain value at the chair's seat is 6.258E – 06, associated with element 35287, while the minimum strain is 1.502E – 10, linked to element 27300. The maximum strain occurs at the center of the seat, indicating that elongation takes place when the seat is subjected to a load. Since the strain value does not exceed the tensile strength of the selected material, which is 6.893E + 01 MPa, the seat model will not break or fail under this applied load.

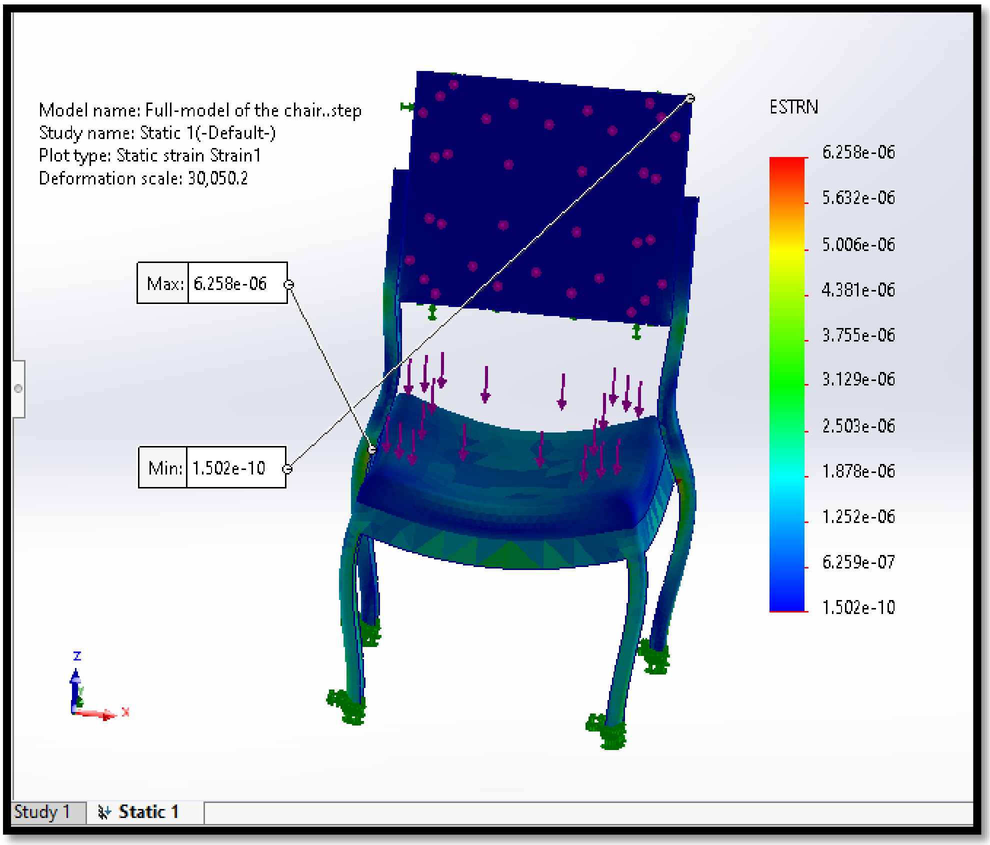


Figure 4.18: Results of strain analysis of the selected sewing chair model

Table 4.17: Results of strain analysis of the selected sewing chair model

Linear static analysis	Value/Units
Tensile strength for the selected material	6.893E + 01 MPa
Max strain of the sewing chair model	6.258E – 06 Element: 35287
Min strain of the sewing chair model	1.502E – 10 Element: 27300

4.4.2.4 Results of Factor of Safety (FOS) analysis for the Selected Sewing Chair Model

The Factor of Safety (FOS) analysis results for the selected sewing chair model are presented in Figure 4.19 and Table 4.18. The maximum FOS value at the chair's seat is 3.000E + 00, associated with node 1, while the minimum FOS is also 3.000E + 00, linked to node 1. The results further indicate a minimum FOS distribution value of 3 from the model analysis. This suggests that the model requires three times the loads applied to deform the selected material, which can be considered within the acceptable safety limits.

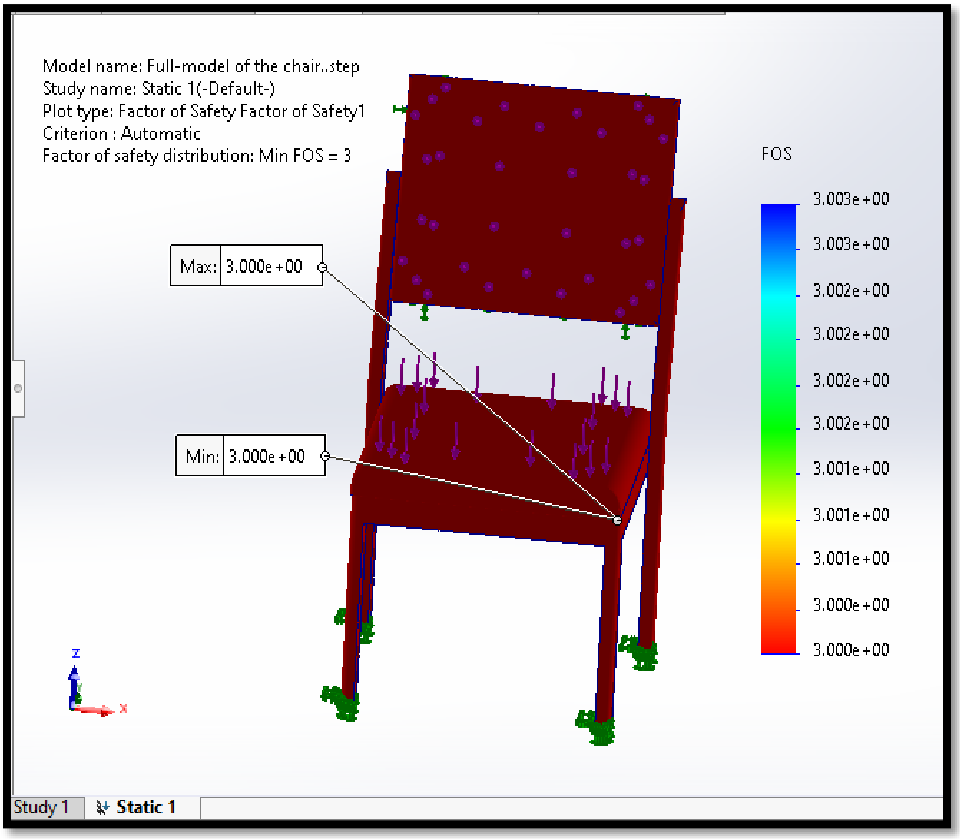


Figure 4.19: Results of FOS analysis of the selected sewing chair model

Table 4.18: Results of FOS analysis of the selected sewing chair model

Linear static analysis	Value/Units
Min FOS distribution for sewing chair model	3
Max FOS of the sewing chair model	1.000 + 00 Node: 1
Min FOS of the sewing chair model	1.000 + 00 Node: 1

4.4.2.5 Comparison of FEA Results of This Study with the Previous Studies

The comparison between the FEA results of this study and previous studies simulating the sewing workstation is presented in Table 4.19. According to several earlier studies by Madara et al., (2016) on an innovative conceptual design of a manual concrete block-making machine; Mohd & Esa, (2021) on design, analysis, and optimisation using SolidWorks simulation of a chair ladder; Mahantesh et al., (2023) on design and modeling using FEA for the sitting posture of computer users from an ergonomic perspective; Paper et al., (2013) on mechanical design and simulation of a two-wheeled wheelchair using SolidWorks; Paper & Aksaray, (2015) on FEA (fatigue) of wooden furniture strength; and Langová et al., (2019) on the construction of wood-based lamella for increased load on seating sewing furniture, these studies found that the maximum stress is less than the yield strength. Therefore, their models will not break or fail due to the applied external loads. This study aligns with previous research, indicating that the maximum stress of the sewing workstation model is less than the yield strength of the selected material. Thus, the proposed sewing chair model will not break or fail under these applied external loads. Furthermore, this study concurs with earlier findings that FEA is the most common analytical tool used to evaluate the strength of redesigned sewing furniture chairs, and the resultant stiffness matrix structural analyses will identify the weak points in the models' structures.

Table 4.19: Comparison of FEA results of this present study with the previous studies

Titles of the studies	Materials used	Human weight applied	FEA Results		References
			Max stress	Remarks	
Innovative Conceptual Design of Manual-Concrete-Block-Making-Machine.	Alloy steel, with yield strength is 620.422 MPa.	981 N applied at the base plate.	0.590262 MPa.	The maximum stress is less than the yield strength. Thus, the part will not broke or fail due the applied external loads.	Madara et al., (2016).
Design, Analysis and Optimisation Using SOLIDWORK Simulation of Chair Ladder.	Pine wood, with the yield strength is 20 MPa.	1500 N applied at the seat.	2.988E + 00 MPa.		Mohd & Esa, (2021).
Design and Modeling Using Finite Element Analysis for the Sitting Posture of Computer Users Based on Ergonomic Perspective.	Aluminium alloy 6061, with the yield strength 276 MPa.	800 N on the base seat and 150 N on the backrest of the seat.	29.99 MPa.		Mahantesh et al., (2023).
Mechanical Design and Simulation of Two-Wheeled Wheelchair Using SolidWorks.	Aluminium alloy 1350, with the yield strength is 27.57 MPa.	980 N on the upper side of the frame.	1.761E – 01 MPa.		Paper et al., (2013).
Finite Element Analysis (Fatigue) of Wooden Furniture Strength.	Scots pine wood, with the yield strength is 72 MPa.	440 N applied on the seat and 330 N applied on the backrest.	40.98 MPa.		Paper & Aksaray, (2015).
Construction of Wood-Based Lamella for Increased Load on Seating Furniture.	Wood, with the yield strength is 23,781 MPa.	150 kg applied on the seat.	28.157 MPa.		Langová et al., (2019).
Ergonomic Redesign of Sewing Workstation for Garments Manufacturing: A Case Study of REAL, Eldoret, Kenya.	Aluminium alloy 6061, with the yield strength is 2.757E + 01 MPa.	800 N on the base seat and 150 N on the backrest of the seat.	7.175E – 01 MPa.		Present study

4.5 Optimizing the Redesign of Workstations for Garment Workers

The results of the optimisation and redesign of workstations for garment-making workers at sewing operations are discussed in detail below:

4.5.1 Optimisation Results

Based on the calculations and the simulation analysis results, the selected sewing chair was optimised using SolidWorks. The overall dimensions of the chosen ergonomic sewing chair model, based on the anthropometric data, have general measurements of 41.65 cm for seat height, 46.20 cm for seat depth, and 47.78 cm for seat width. After successfully running the optimisation, the program cycled through 332 of 332 possible scenarios and provided optimal results as seen in scenario no. 1, which are: The optimal dimensions of the model were 416.5 mm for seat height, 457 mm for seat depth, and 472.8 mm for seat width; the optimal stress of the model, established from the results, was 2.662E+01 MPa; and the optimal mass of the model was 19865.24 g. The optimisation results for this study are presented in Tables 4.20 and Figure 4.20. Additionally, the full report of the optimisation can be found in Appendix XV.

Table 4.20: Optimisation results of sewing chair model for scenarios (1 to 52)

Component name	Units	Current	Initial	Optimal (1)	Scenario1	Scenario2
Height	mm	416.5	416.5	411.5	411.5	412.5
Depth	mm	462	462	457	457	457
Width	mm	477.8	477.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.933	25.933	26.624	26.624	26.149
Mass2	g	19873.34105	19873.34105	19865.23675	19865.23675	19865.69371
Component name	Units	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	457	457	457	457	457
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.542	26.274	26.662	25.873	26.485
Mass2	g	19866.15068	19866.60764	19867.06461	19867.52075	19867.97853
Component name	Units	Scenario8	Scenario9	Scenario10	Scenario11	Scenario12
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	457	457	457	457	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	27.202	26.081	25.916	27.22	26.527
Mass2	g	19868.43468	19868.89246	19869.34942	19869.80639	19867.56487
Component name	Units	Scenario13	Scenario14	Scenario15	Scenario16	Scenario17
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	459	459	459	459	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.945	26.548	25.878	25.974	26.246
Mass2	g	19868.02184	19868.4788	19868.93576	19869.39273	19869.84887
Component name	Units	Scenario18	Scenario19	Scenario20	Scenario21	Scenario22
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	459	459	459	459	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.04	26.956	26.979	25.703	27.249
Mass2	g	19870.30665	19870.7628	19871.22058	19871.67755	19872.13451
Component name	Units	Scenario23	Scenario24	Scenario25	Scenario26	Scenario27
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	461	461	461	461	461
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.883	26.172	26.533	26.123	26.979
Mass2	g	19869.89299	19870.34996	19870.80692	19871.26388	19871.72085
Component name	Units	Scenario28	Scenario29	Scenario30	Scenario31	Scenario32
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	461	461	461	461	461
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.072	26.482	25.783	26.787	26.34
Mass2	g	19872.17699	19872.63478	19873.09092	19873.5487	19874.00567

Component name	Units	Scenario33	Scenario34	Scenario35	Scenario36	Scenario37
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	461	463	463	463	463
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.973	26.532	27.356	27.176	25.88
Mass2	g	19874.46263	19872.22111	19872.67808	19873.13504	19873.59201
Component name	Units	Scenario38	Scenario39	Scenario40	Scenario41	Scenario42
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	463	463	463	463	463
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.949	26.572	26.837	25.854	26.471
Mass2	g	19874.04897	19874.50511	19874.9629	19875.41904	19875.87682
Component name	Units	Scenario43	Scenario44	Scenario45	Scenario46	Scenario47
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	463	463	465	465	465
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.932	26.866	26.889	27.214	26.114
Mass2	g	19876.33379	19876.79075	19874.54924	19875.0062	19875.46316
Component name	Units	Scenario48	Scenario49	Scenario50	Scenario51	Scenario52
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	465	465	465	465	465
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	27.1	25.846	25.8	25.976	26.403
Mass2	g	19875.92013	19876.37709	19876.83323	19877.29102	19877.74716

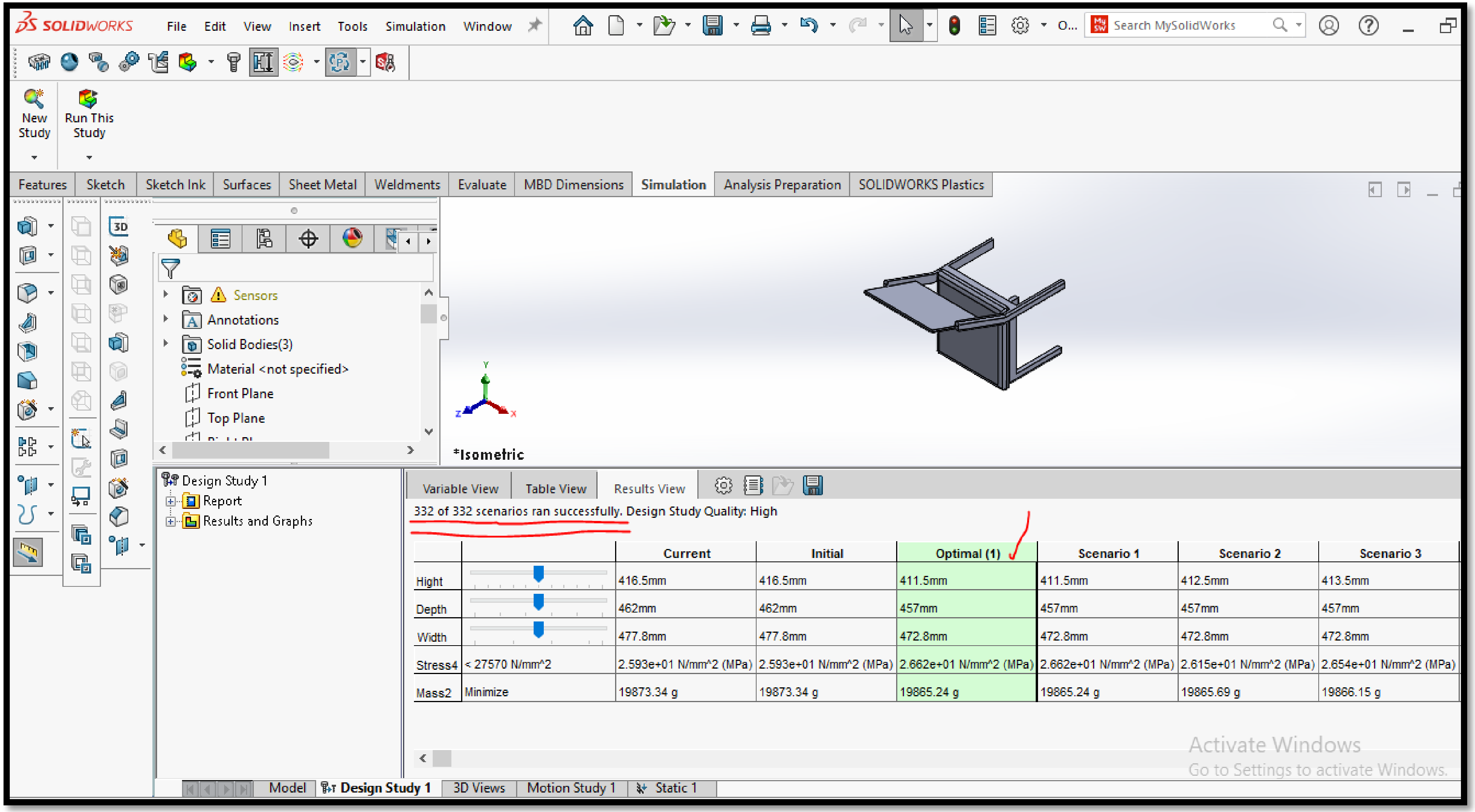


Figure 4.20: Optimisation results of the selected sewing chair model

4.6 Fabricating the Redesign of Workstations for Garment Workers

The results of fabricating the redesign of workstations for garment-making workers at sewing operations are discussed in detail below:

4.6.1 The Complete Sewing Chair Redesign Product

After all the necessary fabrication processes were completed, the final selected redesign of the sewing chair is shown in Figure 4.21.

Figure 4.21: The complete sewing chair redesign product

4.6.2 The Complete Adjustable Sewing Machine Table Redesign Product

After all the necessary fabrication processes were completed, the redesigned adjustable sewing machine table is shown in Figure 4.22.

Figure 4.22: The complete adjustable sewing machine table redesign product

4.6.3 The Complete Assembling of the Sewing Workstation Redesign Product

After the selected sewing chair and adjustable sewing table were fabricated, the redesigned sewing workstation intended for use by the workers at the garment manufacturing facility, REAL, in Eldoret, Kenya, is illustrated in Figure 4.23.

Figure 4.23: The complete assembling of the sewing workstation redesign

4.6.4 Cost Estimation of the Complete Sewing Workstation Redesign Product

The total cost for the fabrication of the proposed sewing workstation (sewing chair and adjustable sewing table) redesign product is presented in Table 4.21 below, assuming the labor cost is 30% of the total material cost. From Table 4.21, it can be seen that the total cost, including materials, labor, and overhead, is 22,501.00 KES (1 USD = 129.00 KES), which is equivalent to USD 174.43. This is more affordable compared to the available sewing workstation (sewing chair and adjustable sewing machine table) redesign products on the market, which range from USD 300.00 to USD 500.00. Additionally, the manufacturability of this proposed sewing workstation redesign product is less time-consuming and more operator-friendly compared to the existing sewing workstation.

Table 4.21: Total cost of the complete sewing workstation redesign product

No.	Items	Size	Quantity	Cost (KES)
1	Wheel	2.5 in	4 pes	1,000.00
2	Washer	14 mm	3 pes	150.00
3	Aluminium (AA 6061)	1 in * 1.5 mm	2 pes/20 ft	4,800.00
4	PVC foam	2 m^2 * 3 in	2 pes/2 m	1,000.00
5	Custom leather upholstery	2 m^2 * 3 in	2 pes/2 m	800.00
6	Thinner	3 liters	1 pes	600.00
7	Wood white oak (flat-sawn)	4 ft * 8 ft * 1 in	2 pes	5,200.00
8	Hinges	¾ in	12 pes	720.00
9	Nuts	1 * 3/4 * 8 mm	12 pes	480.00
10	Screws	2 * ¾ in * 3 mm	12 pes	420.00
11	Paint	2 liters	2 pes	600.00
12	Labor cost			4,731.00
13	Overhead cost			2,000.00
	Total cost			**22,501.00**

4.6.5 The Complete Sewing Workstation Resign Product Specification

Every final product must have its own specifications. In this research, the redesigned sewing workstation product (specifically the sewing chair and adjustable sewing machine table) was categorised into several aspects such as colour, weight, width, and others. The specifications for the redesigned sewing workstation product are shown in Table 4.22 below.

Table 4.22: The complete sewing workstation redesign product specification

Category	Specification
Colour	Black / Red oak
Maximum height of the adjustable sewing table	75.73 cm
Minimum height of the adjustable sewing table	55.73 cm
Height of the sewing chair	41.65 cm
Weight of adjustable sewing table	28 kg
Weight of the sewing chair	19.86 kg
Other specification	Ergonomically redesigned

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This fifth chapter of the thesis summarises the conclusions and recommendations derived from the study's results and analysis. It also highlights areas for further research, limitations and challenges, as well as potential beneficiaries of the study.

5.1 Conclusions

From the results and discussion of this study, the following unique conclusions of the researcher have been drawn based on the specific smart objectives that were achieved through:

1. The analysis of the worker's body posture at the current sewing workstation resulted in a final REBA score of 5, indicating a medium ergonomic risk and the need for changes.
2. The ANOVA tests results were failed to reject the null hypothesis in the data sets ($P > 0.05$). Therefore, there was no significant difference in the anthropometric data. The recommended dimensions for an innovative, ergonomically suitable sewing workstation, redesigned based on anthropometric data, significantly reduced the mismatches between the sewing workstation dimensions and the relevant body dimensions.
3. From the present study, it is anticipated that a criterion determinant for a sewing workstation should be utilised whenever designers and engineers aim to create an ergonomic workstation that incorporates ergonomic principles. This research proposed a redesign of an innovative ergonomically suitable sewing workstation to enhance the match between workstation dimensions and workers' anthropometric characteristics.

4. Analysis of the sitting body posture of the HDM for the proposed ergonomic model yielded a final RULA score of 1, indicating that the ergonomic risk for MSDs was negligible. Thus, this study contributes to the comfort of workers in the workstation. The FEA results demonstrated that the aluminum model passed the test satisfactorily, based on several criteria: the maximum stress was 7.175E-01 MPa and did not exceed the material's yield strength, which was acceptable; the maximum displacement was 3.209E–03 mm, resulting in a maximum deformation of 0.03209 mm, which was below the assigned safety level; the maximum strain derived from the results was 6.258E-06, which can be considered within the acceptable range for the material, indicating that the model would not break or fail due to the applied loads. Additionally, the results established a minimum FOS distribution value of 3 from the model analysis. This implied that the model requires three times the applied loads to deform the selected material, which can be considered within the safety limits.
5. After successfully running the optimisation, the program cycles through all 332 possible scenarios and presents the optimal results found in scenario no. 1: the ideal dimensions of the selected sewing chair model are 416.5 mm for seat height, 457 mm for seat depth, and 472.8 mm for seat width; the optimal stress of the model is 2.662E+01 MPa; and the optimal mass of the selected sewing chair model was 19865.24 g.
6. The sewing workstation redesign product was fabricated and produced using all the necessary manufacturing processes, including the materials selection process, measuring process, cutting process, drilling process, grinding process, assembling process, welding process, painting process, and finishing process. This product

differs from others in the current market because it is an innovative, ergonomically suitable redesigned sewing workstation based on the worker's anthropometric data.

5.2 Recommendation

It is highly recommended that the anthropometric data set from this research be utilised for the redesign of sewing workstations for workers not only in the selected REAL factory in Eldoret, Uasin-Gishu County, but throughout Kenya. This is because the REAL factory chosen for this research is a public facility that promotes equal opportunities for Kenyans from all regions of the country. The data collected for an innovative, ergonomically suitable redesigned sewing workstation should be applicable for all workers in garment manufacturing across Kenya. This will ensure safety, comfort, adaptability, and suitability, ultimately guaranteeing user satisfaction and reducing the incidence of MSDs.

5.3 Areas of Further Research

After the above, unique findings on an innovative ergonomic sewing workstation redesign based on workers' anthropometric data were collected according to ISO 7250-1:2017 international standards. It is therefore fully suggested that in the future, similar scientific research should be conducted in other countries to establish an adequate database of anthropometric measurements. This can assist designers, engineers, and economists in developing solutions for workers who continue to suffer from using un-ergonomically designed workstations in their companies. Additionally, there are many types of materials that can be used in fabricating a sewing workstation. However, the most important factors to consider when selecting materials are strength, durability, and toughness. Lastly, the final redesigned of the sewing workstation should be prepared for the marketing stage, as there are few ergonomic workstation products available in the market.

5.4 Limitations/challenges

Although the unique present research has achieved its objectives and was wisely prepared, there were some limitations that need to be carefully considered in future studies. In addition to designing an innovative, ergonomically suitable sewing workstation based on the workers' anthropometric data, there is also a need to conduct proper sensitization on postures, disabilities, safe practices, and ergonomic methods that promote comfort, health, and safety among sewing workers. Furthermore, during the collection of anthropometric measurements, challenges arose in finding the appropriate time and place for the sewing workers.

5.5 Potential Beneficiaries of the Present Study

While proud and pleased with the unique outcomes of this study, there are hopes that:

- The findings and their procedures have significant implications; thus, the outcomes may contribute to improving ergonomic safety in garment manufacturing and provide comfort to the workers.
- This study can also assist garment manufacturers in enhancing workers’ health and safety.

REFERENCES

3D Static Strength Prediction Program. (1996). Journal of Occupational & Environmental Medicine, 38(1), 101. Retrieved on July 21, 2023 from https://doi.org/10.1097/00043764-199601000-00028

Abid, M., Khan, A., & Hasan, F. (2017). Design Science and Innovation Ergonomics for Improved Productivity Proceedings of Hwwe 2017. Retrieved on May 07, 2022 from http://www.springer.com/series/15399

Ahmad, A., Javed, I., Abrar, U., Ahmad, A., Jaffri, R., & Hussain, A. (2021). Investigation of ergonomic Working Conditions of Sewing and Cutting Machine Operators of Clothing Industry. Industria Textila, 72(3), 309–314. Retrieved on August 20, 2022 from https://doi.org/10.35530/IT.072.03.1723

Ahmadi, R., Iravani, F., & Mamani, H. (2015). Coping With Gray Markets: The Impact of Market Conditions and Product Characteristics. Production and Operations Management, 24(5), 762–777. Retrieved on June 10, 2023 from https://doi.org/10.1111/poms.12319

Ahmed, F. (2018). Improving Workplace Safety Through Ergonomic Intervention- A Case Study of a Readymade Garment Industry. Bangladesh University of Engineering & Technology. Retrieved on October 15, 2023 from https://doi.org/10.1007/s10681-019-2458 6%0Ahttps://www.researchgate.net/publication/273059476%0Ahttps://learning.hccs.edu/faculty/joy.marshall/biol-2320-microbiology-lecture-notes/chapter-3-lecture-notes%0Awww.gscience.net%0Ahttp://www.jim.unsyiah.ac.id/

Akinpelu, A., Oyewole, O., Odole, A., & Ogunbamowo, F. (2016). Work-Related Musculoskeletal Pain and Health-Seeking Behavior Among Nigerian sewing machine operators. Tropical Journal of Medical Research, 19(2), 152. Retrieved on March 12, 2023 from https://doi.org/10.4103/1119-0388.185446

Al-Hinai, N., Al-Kindi, M., & Shamsuzzoha, A. (2018). An ergonomic Student Chair Design and Engineering for Classroom Environment. International Journal of Mechanical Engineering and Robotics Research, 7(5), 534–543. Retrieved on February 13, 2022 from https://doi.org/10.18178/ijmerr.7.5.534-543

Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., & Elsarrag, E. (2016). Occupant Productivity and Office Indoor Environment Quality: A review of the literature. Building and Environment, 105, 369–389. Retrieved on November 28, 2022 from https://doi.org/10.1016/j.buildenv.2016.06.001

Al Madani, D., & Dababneh, A. (2016). Rapid Entire Body Assessment: A literature Review. American Journal of Engineering and Applied Sciences, 9(1), 107–118. Retrieved on April 25, 2023 from https://doi.org/10.3844/ajeassp.2016.107.118

Altincicek, B. (2014). Step by Step Practical Guide With Statistics (from ANOVA to Survival Analysis) in Biological Sciences : Or : Help , How can I analyze my " Damned " Scientific Data Correctly and in an e ... Step by Step Practical Guide With Statistics (from ANOVA to su. September 2013.

Anonymous. (2021). Standard Normal Table. Www.Math.Arizona.Edu, 9998.

Retrieved on March 08, 2023 from https://www.math.arizona.edu/~rsims/ma464/standardnormaltable.pdf

Ansari, A., & Sheikh, J. (2014). Evaluation of work Posture by RULA and REBA: A Case Study. IOSR Journal of Mechanical and Civil Engineering, 11(4), 18–23. Retrieved on January 11, 2024 from https://doi.org/10.9790/1684-11431823

Arezes, M., Dinis-Carvalho, J., & Alves, C. (2015). Workplace Ergonomics in Lean Production Environments: A literature Review. In Work (Vol. 52, Issue 1, pp. 57–70). IOS Press BV. Retrieved on September 02, 2023 from https://doi.org/10.3233/WOR-141941

Aribowo, I., Suhardi, B., & Pujiyanto, E. (2020). Analysis of Working Posture on Musculoskeletal Disorders of Vocational Garment Student's in Garment Assembly Operations Practice. AIP Conference Proceedings, 2217(April). Retrieved on February 09, 2023 from https://doi.org/10.1063/5.0000602

Attwood, A., Deeb, M., & Danz-Reece, M. E. (2003). Ergonomic Solutions for the Process Industries. Ergonomic Solutions for the Process Industries, 1–459. Retrieved on June 21, 2023 from https://doi.org/10.1016/B978-0-7506-7704-2.X5000-4

Baharampour, S., Nazari, J., Dianat, I., & Asgharijafarabadi, M. (2013). Student's Body Dimensions in Relation to Classroom Furniture. Health Promotion Perspectives, 3(2), 165–174. Retrieved on December 26, 2022 from https://doi.org/10.5681/hpp.2013.020

Bailey, R., Shorrock, S., & Fong, K. (2023). Human Factors and Ergonomics. British Journal of Hospital Medicine, 84(6). Retrieved on July 29, 2024 from https://doi.org/10.12968/hmed.2023.0142

Bambura, R., Sujová, E., & Čierna, H. (2020). Utilizing Computer Simulation to Optimize Furniture Production System. BioResources, 15(3), 6752–6765. Retrieved on April 22, 2024 from https://doi.org/10.15376/biores.8.3.6752-6765

Beatrix, E. (2021). Analysis of Rapid Entire Body Assessment (REBA) & Nordic Body Map (NBM) Methods to Reduce Low Back Pain (LBP) In The Stamping and Tooling Company. IOSR Journal of Research & Method in Education, 11(2), 49–54. Retrieved on January 08, 2023 from https://doi.org/10.9790/7388-1102034954

Bendix, T. (1984). Seated Trunk Posture at Various Seat Inclinations, Seat Heights, and Table Heights. Human Factors, 26(6), 695–703. Retrieved on July 16, 2022 from https://doi.org/10.1177/001872088402600609

Berengolts, A., & Lindenbaum, M. (2004). On the Distribution of Saliency. Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2(May). Retrieved on May 21, 2022 from https://doi.org/10.1109/cvpr.2004.1315211

Berlin, C. (2011). Ergonomics Infrastructure. In Technology.Bezerra, G., Carvalho, A., Rocha, V., & Xu, B. (2017). Anthropometry for Children's Clothing: Difficulties and Limitations. IOP Conference Series: Materials Science and Engineering, 254(17). Retrieved on August 04, 2022 from https://doi.org/10.1088/1757-899X/254/17/172001

Biadgo, H., Tsegay, S., Mohammednur, A., & Gebremeskel, F. (2021). Burden of Neck Pain and Associated Factors Among Sewing Machine Operators of Garment Factories in Mekelle City, Northern Part of Ethiopia, 2018, A Cross-Sectional Study. Safety and Health at Work, 12(1), 51–56. Retrieved on February 19, 2023 from https://doi.org/10.1016/j.shaw.2020.10.002

Blanchonette, P. (2010). Jack Human Modelling Tool: A Review. Science And Technology, 1–37. Retrieved on January 01, 2024 from http://www.dtic.mil/dtic/tr/fulltext/u2/a518132.pdf

Borges, L. (1990). Sherlock Holmes. Semiotica, 79(3–4), 213–216. Retrieved on December 13, 2022 from https://doi.org/10.1515/semi.1990.79.3-4.213

Bower, M. (2018). Analysis of Variance (ANOVA) Using Minitab. November. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=32035bdc49dbea680f7418e1cdd2a4a16c8eb8fd7cb586c4e1507ddf8e5a20d8JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Analysis+of+Variance+(+ANOVA+)+Using+Minitab%2c+Bower%2c+M.+(2018).++pdf&u=a1aHR0cHM6Ly93d3cuc2NyaWJkLmNvbS9kb2MvMjM0MjE4NDQvYW5vdmE

Bridger, R. S. (1988). Postural Adaptations to a Sloping Chair and Work Surface. Human Factors, 30(2), 237–247. Retrieved on February 27, 2023 from https://doi.org/10.1177/001872088803000210

Britnell, W., Coady, D., & McDougle, M. (2006). Comparison of Occupational Health and Safety Management Systems. The Synergist, 17(7), 38. Retrieved on November 24, 2022 from https://doi.org/10.3320/1.2759320

Burgess, R. (2018). Participatory Ergonomics: Evidence and Implementation lessons. Applied Ergonomics, 68(February), 289–293. Retrieved on August 03, 2022 from https://doi.org/10.1016/j.apergo.2017.12.009

Burns, M., & Vicente, J. (2000). A Participant-Observer Study of Ergonomics in Engineering Design: - Rules, Types, and Worlds. Applied Ergonomics, 31(1), 73–82.

By, R., & Meister, D. (1995). Experimental Design. This is Followed. July. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=5ad9062935328ec8e7b145565283f87b9b5440ffdde45c75426e0bb42684b776JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=+Experimental+Design+1995+Meister.+pdf&u=a1aHR0cHM6Ly93d3cucmVzZWFyY2hnYXRlLm5ldC9wdWJsaWNhdGlvbi8zMDM1ODk1ODdfUl9BX0Zpc2hlcl9vbl90aGVfRGVzaWduX29mX0V4cGVyaW1lbnRzX2FuZF9TdGF0aXN0aWNhbF9Fc3RpbWF0aW9u

Cañas, J., Velichkovsky, B., & Velichkovsky, M. (2011). Human Factors and Ergonomics. IAAP Handbook of Applied Psychology, July, 316–337. Retrieved on November 23, 2022 from https://doi.org/10.1002/9781444395150.ch13

Caputo, F., Gironimo, G. Di, & Marzano, A. (2006). Ergonomic Optimization of a

Manufacturing System Work Cell in a Virtual Environment. Acta Polytechnica, 46(5). Retrieved on May 29, 2024 from https://doi.org/10.14311/872

Castellucci, I., Arezes, M., & Molenbroek, M. (2015). Equations for Defining the Mismatch Between Students and School Furniture: A Systematic Review. International Journal of Industrial Ergonomics, 48, 117–126. Retrieved on February 11, 2023 from https://doi.org/10.1016/j.ergon.2015.05.002

Castellucci, H., Viviani, C., Arezes, P., Molenbroek, M., Martínez, M., Aparici, V., & Dianat, I. (2020). Applied Anthropometry for Common Industrial Settings Design: Working and Ideal Manual Handling Heights. International Journal of Industrial Ergonomics, 78(April). Retrieved on November 25, 2022 from https://doi.org/10.1016/j.ergon.2020.102963

Castellucci, I., Gonçalves, M., & Arezes, P. (2014). Ergonomic Design of School Furniture. 625–633. Retrieved on December 07, 2022 from https://doi.org/10.1201/ebk1439835074-c68

Ceylan, E., Güray, E., & Kasal, A. (2021). Structural Analyses of Wooden Chairs By Finite Element Method (Fem) and Assessment of the Cyclic Loading Performance Tn Comparison With Allowable Design Loads. Maderas: Ciencia y Tecnologia, 23(February), 1–16. Retrieved on March 30, 2024 from https://doi.org/10.4067/s0718-221x2021000100419

Chaffin, B. (2007). 20087_Ftp. 17(5), 475–484. Retrieved on June 20, 2023 from https://doi.org/10.1002/hfm

Chao, C., & Wang, Y. (2010). An Approach to Estimate Body Dimensions Through Constant Body Ratio Benchmarks. Applied Ergonomics, 42(1), 122–130. Retrieved on July 31, 2023 from https://doi.org/10.1016/j.apergo.2010.05.009

Chen, J., Qiu, J., & Ahn, C. (2017). Construction Worker's Awkward Posture Recognition Through Supervised Motion Tensor Decomposition. Automation in Construction, 77, 67–81. Retrieved on December 31, 2022 from https://doi.org/10.1016/j.autcon.2017.01.020

Cheng, L., Lee, Y., Huang, L., Buckner, A., Lafrenie, M., Dénommée, A., Caswell, M., Want, A., Gan, G., Leong, C., Bee, C., Chin, E., Teh, H., Picco, S., Villegas, L., Tonelli, F., Merlo, M., Rigau, J., Diaz, D., Mathijssen, J. (2016). We are IntechOpen , the World ' s leading Publisher of Open Access Books Built by Scientists , for Scientists TOP 1 %. Intech, 11(tourism), 13. Retrieved on August 31, 2022 from https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

Chuan, K., Hartono, M., & Kumar, N. (2010). Anthropometry of the Singaporean and Indonesian Populations. International Journal of Industrial Ergonomics, 40(6), 757–766. Retrieved on June 29, 2022 from https://doi.org/10.1016/j.ergon.2010.05.001

Chung, Y., & Wong, S. (2007). Anthropometric Evaluation For Primary School Furniture Design. Ergonomics, 50(3), 323–334. Retrieved on December 11, 2022 from https://doi.org/10.1080/00140130600842328

Ciupan, E., Ciupan, C., Campean, E., Stelea, L., Policsek, C., Lungu, F., & Jucan, D.-C. (2018). Opportunities of Sustainable Development of the Industry of

Upholstered Furniture in Romania. A Case Study. Sustainability, 10, 3356. Retrieved on February 23, 2023 from https://doi.org/10.3390/su10093356

Csanády, E., Kovacs, Z., Magoss, E., & Ratnasingam, J. (2019). Optimum Design and Manufacture of Wood Products. Retrieved on May 31, 2024 from https://doi.org/10.1007/978-3-030-16688-5

Das, K. (1996). The Measurement of Flexibility in Manufacturing Systems. 8, 67–93. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=66bdff57a0f519cde22a14542c58d59a70466b6f0240195f3a4ad22f3d703ec8JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=The+Measurement+of+Flexibility+in+Manufacturing+Systems%2c+1996.+pdf&u=a1aHR0cHM6Ly93d3cuc2NpZW5jZWRpcmVjdC5jb20vc2NpZW5jZS9hcnRpY2xlL3BpaS9TMDAwNzg1MDYwNzYwNTEyNQ

Dassault Systemes. (2008). Delmia Virtual Ergonomics Solution. Retrieved on November 30, 2022 from www.3ds.com

De, F., Zicolau, A., & Cury-Boaventura, F. (2015). Stretch Breaks in the Work Setting Improve Flexibility and Grip Strength and Reduce Musculoskeletal Complaints. Motriz. Revista de Educacao Fisica, 21(3), 263–273. Retrieved on December 12, 2022 from https://doi.org/10.1590/S1980-65742015000300007

Del. (2007). Anthropometric Measurement of Filipino Manufacturing Workers. International Journal of Industrial Ergonomics, 37(6), 497–503. Retrieved on January 21, 2023 from https://doi.org/10.1016/j.ergon.2007.02.004

Dergisi, F., & Sciences, A. (2014). Health Status of the Female Workers in the Garment Sector of Bangladesh. Çankırı Karatekin Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 4(1), 43–58. Retrieved on December 21, 2022 from https://www.researchgate.net/publication/282640556

Deros, M., Mohamad, D., Ismail, R., Soon, W., Lee, C., & Nordin, S. (2009). Recommended Chair and Work Surfaces Dimensions of VDT Tasks for Malaysian Citizens. European Journal of Scientific Research, 34(2), 156–167.

Desch, E., & Dinwoodie, M. (1996). Timber Structure, Properties, Conversion and Use. Timber Structure, Properties, Conversion and Use. Retrieved on February 11, 2023 from https://doi.org/10.1007/978-1-349-13427-4

Deschênes, P. (2017). Motion and Time Study, by Ralph M. Barnes, New York, John Wiley and Sons, 1958, 4th Edition, 665 pp. $9.25. Relations Industrielles, 14(1), 164. Retrieved on September 17, 2022 from https://doi.org/10.7202/1022354ar

Dianat, I., Karimi, a., Asl Hashemi, A., & Bahrampour, S. (2013). Classroom furniture and Anthropometric Characteristics of Iranian High School Students: Proposed Dimensions Based on Anthropometric Data. Applied Ergonomics, 44(1), 101–108. Retrieved on November 14, 2022 from https://doi.org/10.1016/j.apergo.2012.05.004

Dianat, I., & Salimi, A. (2014). Working Conditions of Iranian Hand-Sewn Shoe Workers and Associations With Musculoskeletal Symptoms. In Ergonomics (Vol. 57, Issue 4, pp. 602–611). Taylor & Francis. Retrieved on December 18, 2022 from https://doi.org/10.1080/00140139.2014.891053

Dickinson, E., Campion, K., Foster, F., Newman, J., Rourke, T., & Thomas, G. (1992). Questionnaire Development: an Examination of the Nordic Musculoskeletal questionnaire. Applied Ergonomics, 23(3), 197–201. Retrieved on November 04, 2022 from https://doi.org/10.1016/0003-6870(92)90225-K

Dimberg, L., Goldoni, J., Ross, S., & Dimberg, I. (2015). The Changing Face of Office Ergonomics. The Ergonomics Open Journal, 8(1), 38–56. Retrieved on December 21, 2022 from https://doi.org/10.2174/1875934301508010038

Dorjee, B., & Sen, J. (2018). A Study on Nutritional Status Using Anthropometry Among the Limboo Population of Sikkim Philosophy (Science) in Anthropology.

Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, S., Wilson, R., & Van Der Doelen, B. (2012). A strategy for Human Factors/Ergonomics: Developing the discipline and profession. Ergonomics, 55(4), 377–395. Retrieved on December 06, 2022 from https://doi.org/10.1080/00140139.2012.661087

Dutta, D., & Sharma, N. (2023). Impact of Product Packaging on Consumer Buying Behaviour: A Review and Research Agenda. Retrieved on February 11, 2024 from https://doi.org/10.31305/rrijm.2023.v08.n07.009

East, R., & Limited, A. (2020). Report of the Auditor-General on Rivatex East Africa Limited for the year ended 30 June, 2020. 1–9.

Ednah, C., Moronge, M., Ednah, C., & Moronge, M. (2016). Drivers of Performance of Textile Projects in Kenya : A Case of Rivatex East Africa Limited Projects Drivers of Performance of Textile Projects in Kenya : A Case Of Rivatex East Africa Limited Jomo Kenya University of Agriculture and Technology , Kenya Jo. The Strategic Journal Business Change and Management, Vol. 3(1 (12)), 33.

Eladly, M., Abou-Ali, G., Sheta, M., & EL-Ghlomy, H. (2020). A flexible Ergonomic Redesign of the Sewing Machine Workstation. Research Journal of Textile and Apparel, 24(3), 245–265. Retrieved on December 31, 2022 from https://doi.org/10.1108/RJTA-10-2019-0050

Engelmann, F., Breiing, A., & Gutowski, T. (2021). Engineering Design. Springer Handbooks, 629–682. Retrieved on November 29, 2022 from https://doi.org/10.1007/978-3-030-47035-7_16

Ergonomic Workplace Design in An Assembly Line. (2022). Retrieved on September 22, 2025 from https://www.bing.com/ck/a?!&&p=d7ae7af5c5cce2499e075df367c2189388e93096c8ea6b96beb1826fc655d4c7JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Ergonomic+Workplace+Design+in+An+Assembly+Line%2c+2022.+pdf&u=a1aHR0cHM6Ly91cGNvbW1vbnMudXBjLmVkdS9iaXRzdHJlYW1zL2UxNmM5ZTgwLTQ2NTEtNDlhYS04NWM1LWNlNzY4YjUyNzkxZS9kb3dubG9hZA

Esmaeel, A. (2022). An Ergonomic Design of Workplace Layout Based on Anthropometric Measurements: A Literature Review. Journal of Ergonomics, 12(6), 1–3. Retrieved on May 21, 2023 from https://doi.org/10.35248/2165-

7556.22.12.3

Esmaeel, A., & Order, S. (2017a). International Standard technological design —. 2017.

Esmaeel, A., Starovoytova, D., & Asad, M. (2020). Design of Classroom Furniture for Use at Tertiary Institutions. Innovative Systems Design and Engineering, October. Retrieved on September 14, 2022 from https://doi.org/10.7176/isde/11-5-05

Esmaeel, A. (2021). An innovative ergonomic design of classroom desktop-chair and its analysis based on anthropometric measurements at tertiary institutions. case study: Uasin-Gishu County, Kenya. Master's thesis, Moi University. Retrieved on November 23, 2022 from http://ir.mu.ac.ke:8080/jspui/bitstream/123456789/4451/1/Abdalla%27s%20Thesis.pdf

Esmaeel, A., Starovoytova, D., Maube, O., & Asad, R. (2022). An Innovative Ergonomic Design of Classroom Furniture Based on Anthropometric Measurements at Tertiary Institutions. Advances in Phytochemistry, Textile and Renewable Energy Research for Industrial Growth, March, 39–43. Retrieved on March 30, 2023 from https://doi.org/10.1201/9781003221968-5

Esmaeel, A., Starovoytova, D., & Ochola, J. (2024). Design and Simulation Ergonomically Sewing Chair for Garment Manufacturing Workers. 14(1), 67–87. Retrieved on December 18, 2024 from https://doi.org/10.7176/ISDE/14-1-07

Esmaeel, A., Starovoytova, D., Nziu, P., & Ochola, J. (2024). Work-Related Risks and Hazards for Garment Making Workers at Sewing Workstations : A Review . 14(1), 48–66. Retrieved on August 20, 2024 from https://doi.org/10.7176/ISDE/14-1-06

Eswaramoorthi, M., John, M., Rajagopal, A., Prasad, S., & Mohanram, V. (2010). Redesigning Assembly Stations Using Ergonomic Methods as a Lean Tool. Work, 35(2), 231–240. Retrieved on July 21, 2023 from https://doi.org/10.3233/WOR-2010-0975

Eugene, L. (2017). View online : http://dx.doi.org/10.1063/1.5002052 View Table of Contents : http://aip.scitation.org/toc/apc/1883/1 Published by the American Institute of Physics. August. Retrieved on July 22, 2022 from https://doi.org/10.1063/1.5002052

Evaluation, E., & Motion, U. (2023). Applied Sciences Technology. Literature Review. Retrieved on September 17, 2025 from https://www.bing.com/ck/a?!&&p=75d0387c1e7abe9504fd4ce3c521273398b000652c2e4ac99e58c64523315a7bJmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Ergonomics+Evaluation+Using+Motion+Capture+Technology%e2%80%94Literature+Review&u=a1aHR0cHM6Ly93d3cuYWNhZGVtaWEuZWR1LzEwMTcwNjEwMS9Fcmdvbm9taWNzX0V2YWx1YXRpb25fVXNpbmdfTW90aW9uX0NhcHR1cmVfVGVjaG5vbG9neV9MaXRlcmF0dXJlX1Jldmlldw

Eyers, D., & Potter, A. (2017). Industrial Additive Manufacturing: A manufacturing

Systems Perspective. Computers in Industry, 92–93, 208–218. Retrieved on December 21, 2023 from https://doi.org/10.1016/j.compind.2017.08.002

Ezugwu, A., Egba, N., Igweagu, C., Eneje, E., Orji, S., & Ugwu, C. (2020). Awareness of Awkward Posture and Repetitive Motion as Ergonomic Factors Associated With Musculoskeletal Disorders by Health Promotion Professionals. Global Journal of Health Science, 12(6), 128. Retrieved on August 21, 2023 from https://doi.org/10.5539/gjhs.v12n6p128

Fahad, M., & Althuwaini, M. (2025). The relationship of some physical components and anthropometric measurements and the extent of their contribution to the performance of the triple jump competition . 15(1), 13–19.

Fan, C., Mei, Q., Yang, Q., & Li, X. (2022). Computer-Vision Based Rapid Entire Body Analysis (REBA) Estimation. Modular and Offsite Construction (MOC) Summit Proceedings, 90–97. Retrieved on September 23, 2023 from https://doi.org/10.29173/mocs269

Floud, R. (2004). The Origins of Anthropometric History. Social Science History, 28(2), 337–343. Retrieved on November 15, 2022 from https://doi.org/10.1017/s0145553200013195

Fulder, T., Pizmoht, P., Polajnar, A., & Leber, M. (2005). Ergonomically designed Workstation Based on Simulation of Worker's Movements. International Journal of Simulation Modelling, 4(1), 27–34. Retrieved on February 27, 2024 from https://doi.org/10.2507/IJSIMM04(1)3.038

Fulton, J., & Marsh, M. (2000). Scenario Building as An Ergonomics Method in Consumer Product Design. Applied Ergonomics, 31(2), 151–157. Retrieved on June 03, 2023 from https://doi.org/10.1016/S0003-6870(99)00035-6

Gade, R., Chandurkar, P., Upasani, H., & Khushwaha, D. (2015). Ergonomic Intervention to Improve Safety and Productivity. International Journal on Textile Engineering and Processes, 1(3), 79–88.

Gawroński, T. (2013). Optimisation of CNC Routing Operations of Wooden Furniture Parts. International Journal of Advanced Manufacturing Technology, 67(9–12), 2259–2267. Retrieved on May 13, 2024 from https://doi.org/10.1007/s00170-012-4647-5

Ghoual, A. (2019). The effect of Repetition Ranges on Maximal Strength and Hypertrophy. International Journal of Physical Education, Fitness and Sports, October, 149–157. Retrieved on March 05, 2023 from https://doi.org/10.26524/ijpefs19415

Gok. (2015). Kenya Apparel and Textile Industry. Ministry of Industrialization and Enterprise Development, 1–68. Retrieved on November 10, 2022 from www.wbginvestmentclimate.org

Gopura, R., & Amarasena, K. (2008). Design of an Ergonomically Efficient Chair. 14th ERU Symposium, January 2008, 12–14.

Gorce, P., Jacquier-Bret, J., & Merbah, J. (2022). A predictive Model to Quantify Joint Torques and Support Reaction Forces When Using a Smartphone While Standing With Support. Ergonomics, 65(4), 531–545. Retrieved on March 21, 2023 from https://doi.org/10.1080/00140139.2021.1963845

Gouvali, K., & Boudolos, K. (2006). Match Between School Furniture Dimensions and Children's Anthropometry. Applied Ergonomics, 37(6), 765–773. Retrieved on December 26, 2022 from https://doi.org/10.1016/j.apergo.2005.11.009

Greggi, C., Visconti, V., Albanese, M., Gasperini, B., Chiavoghilefu, A., Prezioso, C., Persechino, B., Iavicoli, S., Gasbarra, E., Iundusi, R., & Tarantino, U. (2024). Work-Related Musculoskeletal Disorders : A Systematic Review and Meta-Analysis.

Gross, D., Jardim Nunes, N., Sigchi (Group : U.S.), & Association for Computing Machinery. (2011). TEI '11 : Fifth International Conference on Tangible, Embedded and Embodied Interaction, January 23-26, 2011, Madeira, Portugal. Association for Computing Machinery.

Gupta, D. (2014). Anthropometry and the Design and Production of Apparel: An overview. In Anthropometry, Apparel Sizing and Design (Issue 2005). Woodhead Publishing Limited. Retrieved on August 09, 2022 from https://doi.org/10.1533/9780857096890.1.34

Habib, M. (2015). Case Study Ergonomic Risk Factor Identification for Sewing Machine Operators Through Supervised Occupational Therapy Fieldwork in Bangladesh : A Case Study. 50, 357–362. Retrieved on November 15, 2022 from https://doi.org/10.3233/WOR-151991

Halpern, A., & Dawson, D. (1997). Design and Implementation of a Participatory Ergonomics Program for Machine Sewing Tasks. International Journal of Industrial Ergonomics, 20(6), 429–440. Retrieved on July 21, 2023 from https://doi.org/10.1016/S0169-8141(96)00070-4

Hambali, H., Mohamad, E., & Ito, T. (2021). Ergonomic Design for Assembly Manufacturing Workstation Based on Universal Design Principles. In Lecture Notes in Networks and Systems (Vol. 260, Issue July). Springer International Publishing. Retrieved on February 17, 2023 from https://doi.org/10.1007/978-3-030-80829-7_106

Hambali, H., Rahim, A., Azizan, N., Zali, Z., Akmal, S., & Zin, H. (2019). Analysis the Awkward Posture Ergonomic Risk and Workstation Improvement Simulation in Mechanical Assembly Manufacturing Industry using DelmiaV5. IOP Conference Series: Materials Science and Engineering, 705(1), 0–6. Retrieved on September 10, 2022 from https://doi.org/10.1088/1757-899X/705/1/012044

Hanson, L., Sperling, L., Gard, G., Ipsen, S., & Olivares Vergara, C. (2009). Swedish Anthropometrics for Product and Workplace Design. Applied Ergonomics, 40(4), 797–806. Retrieved on August 21, 2022 from https://doi.org/10.1016/j.apergo.2008.08.007

Harada, N., & Griffin, J. (1991). Vibration. 185–192. Retrieved on September 15, 2025 from https://www.bing.com/ck/a?!&&p=4f090e74990560ce5cb2b03bc1db290067544957de432e8f74e65013916590e6JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-

ab2b217a617a&psq=Factors+influencing+vibration+sense+thresholds+used+to+assess+occupational+exposures+to+hand+transmitted+vibration.+pdf&u=a1aHR0cHM6Ly9wbWMubmNiaS5ubG0ubmloLmdvdi9hcnRpY2xlcy9QTUMxMDM1MzQ3Lw

Haraga, G., & Goantă, M. (2017). FEA Analysis and Design Optimization for a Multifunctional Piece of Furniture. MATEC Web of Conferences, 112. Retrieved on May 23, 2024 from https://doi.org/10.1051/matecconf/201711206009

Harari, Y., Bechar, A., Raschke, U., & Riemer, R. (2017). Automated simulation-based Workplace Design that Considers Ergonomics and Productivity. International Journal of Simulation Modelling, 16(1), 5–18. Retrieved on March 30, 2024 from https://doi.org/10.2507/IJSIMM16(1)1.355

Harrison, J., Yu, F., Chan, J., & Rempel, M. (2008). A Randomized Controlled Trial of Chair. April. Retrieved on June 29, 2023 from https://doi.org/10.1097/JOM.0b013e318163869a

Haslegrave, M., & Holmes, K. (1994). Integrating Ergonomics and Engineering in the Technical Design Process. Applied Ergonomics, 25(4), 211–220. Retrieved on November 23, 2022 from https://doi.org/10.1016/0003-6870(94)90002-7

Helander, G. (1997). Forty Years of IEA: Some Reflections on The Evolution of Ergonomics. Ergonomics, 40(10), 952–961. Retrieved on July 22, 2023 from https://doi.org/10.1080/001401397187531

Herbert, R., Dropkin, J., Warren, N., Sivin, D., Doucette, J., Kellogg, L., Bardin, J., Kass, D., & Zoloth, S. (2001). Impact of a Joint Labor-Management Ergonomics Program on Upper Extremity Musculoskeletal Symptoms Among Garment Workers. 32, 453–460.

Hignett, S., & McAtamney, L. (2000). Rapid Entire Body Assessment (REBA). Applied Ergonomics, 31(2), 201–205. Retrieved on December 23, 2022 from https://doi.org/10.1016/S0003-6870(99)00039-3

Hildebrandt, H., Bongers, M., Van Dijk, H., Kemper, G., & Dul, J. (2001). Dutch Musculoskeletal Questionnaire: Description and Basic Qualities. Ergonomics, 44(12), 1038–1055. Retrieved on November 20, 2022 from https://doi.org/10.1080/00140130110087437

Hiremath, L., & Hiremath, D. (2012). Noncommunicable Diseases. Essentials of Community Medicine: A Practical Approach, 76–76. Retrieved on January 19, 2025 from https://doi.org/10.5005/jp/books/11660_5

Hoff, V., & Öberg, K. (2015). The Role of The Physical Work Environment For Creative Employees – A Case Study of Digital Artists. International Journal of Human Resource Management, 26(14), 1889–1906. Retrieved on December 17, 2022 from https://doi.org/10.1080/09585192.2014.971842

Homkhiew, C., Ratanawilai, T., & Pochana, K. (2012). Application of a Quality Function Deployment Technique to Design and Develop Furniture Products. 34(6), 663–668.

Hse. (2005). HSE Health & Safety Executive Revision of Body Size Criteria in

Standards-Protecting People Who Work At Height.

Hsiao, H., Long, D., & Snyder, K. (2002). Anthropometric Differences Among Occupational Groups. Ergonomics, 45(2), 136–152. Retrieved on July 21, 2019 from https://doi.org/10.1080/00140130110115372

Hsu, W., & Yu, Y. (2010). Hand Surface Area Estimation Formula Using 3d Anthropometry. Journal of Occupational and Environmental Hygiene, 7(11), 633–639. Retrieved on January 22, 2023 from https://doi.org/10.1080/15459624.2010.514259

Hsue, W., Pelzek, E., Siess, S., Terhaar, A., Mintz, B., & Pariaut, R. (2025). Effect of additional dimensions and views in the echocardiographic determination of 3-dimensional left ventricular volume in myxomatous mitral valve disease in dogs. Journal of Veterinary Internal Medicine, 39(1), 1–12. Retrieved on January 30, 2025 from https://doi.org/10.1111/jvim.17300

Huang, L., & Intarakumnerd, P. (2019). Alternative Technological Learning Paths of Taiwanese Firms. Asian Journal of Technology Innovation, 27, 1–14. Retrieved on December 22, 2022 from https://doi.org/10.1080/19761597.2019.1678390

Hunter, S. (2008). The Toyota Production System Applied to the Upholstery Furniture Manufacturing Industry. Materials and Manufacturing Processes, 23, 629–634. Retrieved on July 21, 2023 from https://doi.org/10.1080/10426910802316476

Iancu, C. (2017). About optimization design study on solidworks. 1, 199–206. Retrieved on September 16, 2025 from https://www.bing.com/ck/a?!&&p=4b1d8a84ad423a2179a65e2aa9d6ab83348c94f7699176314b830ca24b2d2417JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=About+optimization+design+study+on+solidworks%2c+2017.+pdf&u=a1aHR0cHM6Ly93d3cudXRnaml1LnJvL3Jldl9tZWMvbWVjYW5pY2EvcGRmLzIwMTctMDEvMzFfQyVjNCU4M3QlYzQlODNsaW4lMjBJQU5DVSUyMC0lMjBBQk9VVCUyME9QVElNSVpBVElPTiUyMERFU0lHTiUyMFNUVURZJTIwT04lMjBTT0xJRFdPUktTLnBkZg

Iancu, C., & Gutsalenko, Y. (2019). About Optimization Variants in Solidworks Simulationexpress Vs. Simulation Module. Academica Brâncuşi, 2(1844 – 640X), 19–24.

Iberes, S., & Giovana dos Santos, S. (2000). Anthropometry and Biomechanics: Characteristics, Principles and Anthropometric Models. Revista Brasileira de Cineantropometria e Desempenho Humano.

Igbokwe, J., Igbokwe, O., Osueke, O., Opara, V, Ileagu, O., & Ezeakaibeya, U. (2019). Considerations of Anthropometrics in the Design of Lecture Hall Furniture. International Journal of Research-Granthaalayah, 7(8), 374–386. Retrieved on November 25, 2022 from https://doi.org/10.5281/zenodo.3401350

Interaction Design Foundation. (2017). How to Design for Ease of Use. Retrieved on August 14, 2023 from https://doi.org/10.1016/B978-0-12-813296-8/00016-5

İşeri, A., & Arslan, N. (2009). Estimated Anthropometric Measurements of Turkish Adults and Effects of Age and Geographical Regions. International Journal of Industrial Ergonomics, 39(5), 860–865. Retrieved on December 26, 2022 from https://doi.org/10.1016/j.ergon.2009.02.007

Ismaila, O., Musa, I., Adejuyigbe, B., & Akinyemi, D. (2013). Anthropometric Design of Furniture for Use in Tertiary Institutions in Abeokuta, South-Western Nigeria. Engineering Review, 33(3), 179–192.

Javidinejad, A., & Ph, D. (2021). International Journal of Aerospace and Mechanical Engineering Review of Finite Element Modeling and Analysis Applications in Aerospace Structural Systems Design : Design Conceptualization Tool International Journal of Aerospace and Mechanical Engineering. 8(2), 14–20.

Jilcha, K., & Kitaw, D. (2016). A literature Review on Global Occupational Safety and Health Practice & Accidents Severity. International Journal for Quality Research, 10(2), 279–310. Retrieved on November 03, 2023 from https://doi.org/10.18421/IJQR10.02-04

Johan, M., & Renate, de B. (2005). Enhancing the Use of Anthropometric Data. Human Factors in Design, Safety, and Management, January 2000, 289–297. Retrieved on October 08, 2022 from https://doi.org/10.1017/CBO9781107415324.004

John, M., Paul, P., Kumar, V., Oommen, M., & Athira, P. (2020). Design and Ergonomic Analysis of an Assistive Commode. 4, 632–635. Retrieved on September 30, 2023 from https://doi.org/10.35940/ijitee.D1333.029420

Kahare, W. (2014). Assessment of the Role of Strategic Ergonomics on Employee Performance in the Health Sector in Kenya : A Study of Health Workers in Nakuru County. International Journal of Science and Research (IJSR), 3(10), 2101–2107.

Kalınkara, V., Çekal, N., Akdoğan, I., & Kacar, N. (2011). Anthropometric Measurements Related to The Workplace Design For Female Workers Employed in The Textiles Sector in Denizli, Turkey. Eurasian Journal of Anthropology Eurasian J. Anthropol, 2(2), 102–111.

Kanduč, T., & Rodič, B. (2015). Manufacturing Processes Optimisation in a Furniture Factory. Applied Modelling and Computing in Social Sciences, January, 23–33. Retrieved on April 24, 2024 from https://doi.org/10.3726/978-3-653-05821-5

Kaprol, T. (2016). Historical Development of Furniture in the Context of Narrow , Historical Development of Furniture in the Context of Narrow , Restriction and Transformation Concepts × Dar , Kisitlilik VeDönüşebilme Kavramlari Bağlaminda MobilyaninTarihsel. October.

Kapuria, K. (2018). Ergonomic Design of Table and Chair based on QFD and Anthropometric Measurement and Improved Facility Layout. Ergonomics International Journal, 2(3), 1–14. Retrieved on July 21, 2023 from https://doi.org/10.23880/eoij-16000146

Kaya, Ö. (2015). Design of Work Place and Ergonomics in Garment Enterprises. Procedia Manufacturing, 3(January), 6437–6443. Retrieved on December 31, 2022 from https://doi.org/10.1016/j.promfg.2015.07.921

Keir, J., Farias Zuniga, A., Mulla, M., & Somasundram, G. (2021). Relationships and Mechanisms Between Occupational Risk Factors and Distal Upper Extremity Disorders. Human Factors, 63(1), 5–31. Retrieved on September 25, 2023 from https://doi.org/10.1177/0018720819860683

Khadem, M., & Islam, A. (2014). Development of Anthropometric data for Bangladeshi male Population. International Journal of Industrial Ergonomics, 44(3), 407–412. Retrieved on November 23, 2022 from https://doi.org/10.1016/j.ergon.2014.01.007

Khan, F., Ghanem, S., & Garaniya, V. (2022). Advances in Behavioral Based Safety. in Advances in Behavioral Based Safety. Retrieved on March 01, 2023 from https://doi.org/10.1007/978-981-16-8270-4

Kinnunen, M., & Liira, J. (2014). Work-Related Stress Management by Finnish Enterprises. Industrial Health, 52(3), 216–224. Retrieved on December 15, 2022 from https://doi.org/10.2486/indhealth.2013-0178

Klamklay, J., Sungkhapong, A., Yodpijit, N., & E. Patterson, P. (2008). Anthropometry of the Southern Thai population. International Journal of Industrial Ergonomics, 38(1), 111–118. Retrieved on September 13, 2022 from https://doi.org/10.1016/j.ergon.2007.09.001

Koc, B., & Liu, B. (2013). Hand-Arm Vibration Measurements and Analysis Using Smartphones Written for Presentation at the 2013 ASABE Annual International Meeting Sponsored by ASABE Kansas City, Missouri. 7004.

Koirala, R. (2022). A Literature Review on Ergonomics , Ergonomics Practices , and Employee Performance. 273–288.

Komlos, J. (2018). The New Palgrave Dictionary of Economics. The New Palgrave Dictionary of Economics, October. Retrieved on April 07, 2023 from https://doi.org/10.1057/978-1-349-95189-5

Koren, Y., Gu, X., & Guo, W. (2017). Reconfigurable Manufacturing Systems: Principles, Design, and Future Trends. Frontiers of Mechanical Engineering, 13. Retrieved on June 26, 2023 from https://doi.org/10.1007/s11465-018-0483-0

Krishna, T. (2019). Chapter 1. January. Retrieved on September 13, 2025 from https://www.researchgate.net/publication/329522217_Ergonomics_work_place_engineering_in_Garment_industry?enrichId=rgreq-df2401fe01abce99404cb06b9bccfbd9-XXX&enrichSource=Y292ZXJQYWdlOzMyOTUyMjIxNztBUzo3MTg0OTE1OTg0NjcwNzJAMTU0ODMxMzE1NDQ2Ng%3D%3D&el=1_x_3&_esc=publicationCoverPdf

Kumar, B. (2018). Fundamentals of Packaging Technology.

Kuorinka, Ii. (2000). History of the International Ergonomics Association - The First Quarter of a Century. (p. 178). Retrieved on September 10, 2023 from htto://ergonomics-iea.org

Kurban, H., Tankut, N., & Melemez, K. (2015). Ergonomic and structural Analysis of Classroom Furniture: A Case Study For High Schools in Bartin, Turkey. Research for Furniture Industry 27th International Conference, December.

Kureshi, O., Khan, S., & Madavi, S. (2014). Design and Fabrication of Multipurpose Portable Wooden Table. 1(July), 52–56.

Kusuma, T. (2020). Analysis of Body Posture Using Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) to Improve the Posture of Sand Paper Machine Operators and Reduce the Risk of Low Back Pain. Biology, Medicine, & Natural Product Chemistry, 9(1), 21–25. Retrieved on December 15, 2023 from https://doi.org/10.14421/biomedich.2020.91.21-25

Langová, N., Réh, R., Igaz, R., Krišťák, L., Hitka, M., & Jošcák, P. (2019). Construction of Wood-Based Lamella For Increased Load on Seating Furniture. Forests, 10(6). Retrieved on November 18, 2023 from https://doi.org/10.3390/f10060525

Latinovic, T., Parhi, R., & Srinivas, J. (2015). Master Thesis Design , Analysis and Fabrication of an Articulated. May. Retrieved on November 29, 2022 from https://doi.org/10.13140/RG.2.1.4918.9286

Leilanie, J. (2004). Risk factors to musculoskeletal disorders and anthropometric measurements of filipino manufacturing workers. International Journal of Occupational Safety and Ergonomics, 10(4), 349–359. Retrieved on December 13, 2022 from https://doi.org/10.1080/10803548.2004.11076618

Levanon, Y., Lerman, Y., Gefen, A., & Ratzon, N. Z. (2014). Validity of the Modified RULA for Computer Workers and Reliability of One Observation Compared to Six. Ergonomics, 57(12), 1856–1863. Retrieved on January 26, 2024 from https://doi.org/10.1080/00140139.2014.952350

Li, G., Haslegrave, M., & Corlett, N. (1995). Factors Affecting Posture for Machine Sewing Tasks. The need for changes in sewing machine design. Applied Ergonomics, 26(1), 35–46. Retrieved on August 05, 2022 from https://doi.org/10.1016/0003-6870(94)00005-J

Li, H., Zhang, Q., Chong, C., Yap, R., Tay, K., Hang, T., Edwin, T., Olivier, A., Yap, R., Tay, B. K., Edwin, T., Olivier, A., Baillargeat, D., Pro, D., Arulkumar, S., Parthiban, S., Goswami, A., Varma, S., Naushad, M., Prakash, C. (2019). Ac ce pte d M us pt. Materials Today: Proceedings, 22(1), 16–20. Retrieved on January 30, 2025 from https://doi.org/10.1080/10584587.2018.1514889%0Ahttps://doi.org/10.1016/j.matpr.2019.12.188%0Ahttps://doi.org/10.1016/j.matpr.2019.09.090%0Ahttps://doi.org/10.1080/14484846.2018.1432089

Lindh, M., Markhede, G., Hospital, C., Medicine, S., Medicine, R., & Hospital, S. (1991). Neck and Shoulder Complaints Among Sewing-Machine Operators. August, 251–257.

Lu, P. (2003). Risk factors for Low Back Pain Among Filipino Manufacturing Workers and Their Anthropometric Measurements. Applied Occupational and Environmental Hygiene, 18(3), 170–176. Retrieved on November 06, 2022 from https://doi.org/10.1080/10473220301349

Lundgren, K., Kuklane, K., Gao, C., & Holmér, I. (2013). Effects of Heat Stress on Working Populations When Facing Climate Change. Industrial Health, 51(1), 3–15. Retrieved on September 26, 2022 from https://doi.org/10.2486/indhealth.2012-0089

M. Ali, S. Rahman, S. Parvez, H. (2014). Ergonomic Design of Garments Furniture For

Bangladeshi Workers Based on Anthropometric Measurement. Internatinal Conference on Mechanical , Industrial and Energy Engineering, May, 1–5.

Madara, S. (2016). Consumer-Perception on Polyethylene-Shopping-Bags Consumer-Perception on Polyethylene-Shopping-Bags. November.

Madara, S., Arusei, K., & Njoroge, N. (2016). Design Simulation and Analysis of Manual Block-Making Machine Design Simulation and Analysis of Manual block-making machine. August.

Mahantesh, M., Rao, R., Chandra, P., Vijayakumar, N., Nandini, B., Prasad, D., & Vasudev, H. (2023). Design and Modeling Using Finite Element Analysis For the Sitting Posture of Computer Users Based on Ergonomic Perspective. International Journal on Interactive Design and Manufacturing. Retrieved on August 21, 2024 from https://doi.org/10.1007/s12008-023-01383-9

Malik, N., Maan, A., Pasha, S., Akhtar, S., & Ali, T. (2010). Role of Hazard Control Measures in Occupational Health and Safety in The Textile Industry of Pakistan Role of Hazard Control Measures in Occupational Health and Safety in the Textile Industry of Pakistan. August 2019.

Man, C. (2011). Anthropometry and Workspace Design Normal Man ? Anthropometry Static (Structural) Anthropometry Dynamic (Functional) Anthropometry Non-normal Distributions Stature Distributions Stature Distributions Anthropometric Diversity. Design, August, 1–8.

Manivel, K. (2019). Ergonomic Considerations for Design of Industrial Workstation. International Research Journal of Engineering and Technology (IRJET), 04(September).

Manzoor, R., & Reddy, K. (2019). Digital Human Modeling in Ergonomic Risk Assessment of Working Postures Using RULA. Proceedings of the International Conference on Industrial Engineering and Operations Management, 2019(MAR), 2714–2725.

Marshall, M., & Armstrong, J. (2004). Observational Assessment of Forceful Exertion and the Perceived Force Demands of Daily Activities. Journal of Occupational Rehabilitation, 14(4), 281–294. Retrieved on October 11, 2022 from https://doi.org/10.1023/B:JOOR.0000047430.22740.57

Mayfield, T. (2007). Bodyspace: Anthropometry, Ergonomics and the Design of Work (3rd ed.) by Stephen Pheasant & Christine M. Haslegrave 2005, 332 pages, $69.95 Boca Raton, FL: CRC Press ISBN 0-415-28520-8. Ergonomics in Design: The Quarterly of Human Factors Applications, 15(2), 30–30. Retrieved on July 13, 2023 from https://doi.org/10.1177/106480460701500210

McAtamney & Hignett. (2000). REBA Employee Assessment Worksheet. Applied Ergonomics, 31(816), 201–205. Retrieved on February 23, 2023 from http://ergo-plus.com/wp-content/uploads/REBA.pdf

McAtamney, L., & Hignett, S. (2004). Rapid Entire Body Assessment. Handbook of Human Factors and Ergonomics Methods, 31, 8-1-8–11. Retrieved on November 20, 2023 from https://doi.org/10.1201/9780203489925.ch8

Mehta, K. (2016). Integrating Physical and Cognitive Ergonomics. IIE Transactions on

Occupational Ergonomics and Human Factors, 4(2–3), 83–87. Retrieved on October 08, 2022 from https://doi.org/10.1080/21577323.2016.1207475

Merino, P., Artazcoz, L., Cornelio, C., Iñiguez, I., Rojas, M., Martínez-Iñigo, D., Vives, A., Funcasta, L., & Benavides, G. (2017). Work and Health in Latin America: Results From the Working Conditions Surveys of Colombia, Argentina, Chile, Central America and Uruguay. Occupational and Environmental Medicine, 74(6), 432–439. Retrieved on January 22, 2023 from https://doi.org/10.1136/oemed-2016-103899

Michael, M., Porter, D., & Pountney, E. (2007). Tilted Seat Position For Non-Ambulant Individuals With Neurological and Neuromuscular Impairment: A Systematic Review. Clinical Rehabilitation, 21(12), 1063–1074. Retrieved on October 29, 2022 from https://doi.org/10.1177/0269215507082338

Middlesworth, M. (2014). A Step-by-Step Guide Rapid Entire Body Assessment (REBA). Ergonomics Plus Inc, 31, 1–11.

Mihartescu, A., Liviu Negrut, M., & Misca, M. (2021). The Workspaces and Their Influence on Employee'S Work Productivity. Acta Technica Napocensis, 64(Special I), 165–170.

Milanese, S., & Grimmer, K. (2004). School Furniture and the User Population: An anthropometric perspective. Ergonomics, 47(4), 416–426. Retrieved on June 11, 2023 from https://doi.org/10.1080/0014013032000157841

Miller, K. (1989). Furniture Manufacturing. In Industrial Robot Handbook. Retrieved on April 23, 2023 from https://doi.org/10.1007/978-1-4684-6608-9_75

Mohamad, D., Md Deros, B., Ismail, R., Daruis, I., & Sukadarin, H. (2013). RULA Analysis of Work-Related Disorder Among Packaging Industry Worker Using Digital Human Modeling (DHM). Advanced Engineering Forum, 10(December 2014), 9–15. Retrieved on July 28, 2023 from https://doi.org/10.4028/www.scientific.net/aef.10.9

Mohamed, G., Munasinghe, P., & Abeysekara, D. (2010). Designing Chairs With Mounted Desktop For University Students: Ergonomics and Comfort. International Journal of Industrial Ergonomics, 40(1), 8–18. Retrieved on September 29, 2023 from https://doi.org/10.1016/j.ergon.2009.10.003

Mohammadi, S., Al-e-Hashem, M., & Rekik, Y. (2020). An Integrated Production Scheduling and Delivery Route Planning With Multi-Purpose Machines: A Case Study From a Furniture Manufacturing Company. In International Journal of Production Economics (Vol. 219). Retrieved on November 14, 2022 from https://doi.org/10.1016/j.ijpe.2019.05.017

Mohd, D., & Esa, F. (2021). Design , Analysis and Optimization Using Solidwork Simulation of Chair Ladder. Uthm, 2(2), 947–957. Retrieved on June 21, 2024 from https://penerbit.uthm.edu.my/periodicals/index.php/peat/article/view/946/1477

Mousumi, N. (2015). Anthropometric Measurement Among Sewing Machine Operators of Garment Workers In Bangladesh.

Musa, I., & Ismaila, O. (2014). Student Anthropometric Data and Furniture Mismatches in Selected Institutions in Abeokuta, Ogun State, Nigeria. Theoretical Issues in Ergonomics Science, 15(2), 205–213. Retrieved on February 23, 2023 from https://doi.org/10.1080/1463922X.2011.611272

Musau, G. (2018). Supply Chain Determinants of Organizational Performance among Textile Manufacturing Firms in Kenya. The Moderating Effect of Background Characteristics. The Moderating Effect of Background Characteristics.

Musgraves, D., Hu, J., & Calvez, L. (2019). Springer Handbook of Glass. Retrieved on September 18, 2025 from https://www.bing.com/ck/a?!&&p=09d15bc8ac5520948507f1821a2d58e9d259435753d8b576497ad6dab0e015afJmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Springer+Handbook+of+Glass%2c+2019.+pdf&u=a1aHR0cHM6Ly9saW5rLnNwcmluZ2VyLmNvbS9ib29rLzEwLjEwMDcvOTc4LTMtMzE5LTkzNzI4LTE

Mustafa. (2012). Finite Element Analysis of Wooden Chair Strength In Free Drop. International Journal of the Physical Sciences, 7(7), 1105–1114. Retrieved on April 02, 2024 from https://doi.org/10.5897/ijps11.1229

Nadadur, G., & Parkinson, B. (2013). The role of Anthropometry in Designing For Sustainability. Ergonomics, 56(3), 422–439. Retrieved on November 13, 2022 from https://doi.org/10.1080/00140139.2012.718801

Nanyang Technology University. (2014). Design Concept Synthesis. 1–19. Retrieved on October 14, 2022 from http://www.ntu.edu.sg/home/mkhheng/mp4011/Design_Synthesis.pdf

Natsuda, K., Goto, K., & Thoburn, T. (2010). Challenges to the Cambodian Garment Industry in the Global Garment Value Chain. College of International Management Ritsumeikan Asia Pacific University, Japan School of International Development , University of East Anglia , UK. May. Retrieved on September 16, 2022 from https://doi.org/10.1057/ejdr.2010.21

Nickpour, F., & Dong, H. (2011). Designing Anthropometrics! Requirements Capture For Physical Ergonomic Data For Designers. Design Journal, 14(1), 92–111. Retrieved on Octoper 25, 2022 from https://doi.org/10.2752/175630610X12877385838849

Norhidayah, S., Nik Mohamed, Z., Mansor, A., & Ismail, R. (2016). RULA: Postural loading assessment tools for Malaysia mining industry. Journal of Engineering Science and Technology, 11(April), 1–8.

Of, A., Process, A., & Data, U. (2019). Application of Data Glove For Assembly Analysis of Selected Component. 2946–2951. Retrieved on October 11, 2023 from https://doi.org/10.17973/MMSJ.2019

Of, Alberta, G. (2021). Ergonomics in the Workplace: Identifying and Controlling MSI Hazards Classification: Public Ergonomics in the Workplace: Identifying and Controlling MSI Hazards OHS Information For Employers and Supervisors Why Prevent MSIs?

Of, D., & Student, A. (2021). Ergonomically Consideration of Design of Adjustable Student Chair.

Okareh, T., Solomon, E., & Olawoyin, R. (2021). Prevalence of Ergonomic Hazards and Persistent Work-Related Musculoskeletal Pain Among Textile Sewing Machine Operators. Safety Science, 136(January), 105159. Retrieved on May 28, 2023 from https://doi.org/10.1016/j.ssci.2021.105159

Oyewole, A., Haight, M., & Freivalds, A. (2010). The Ergonomic Design of Classroom Furniture/Computer Work Station For First Graders in the Elementary school. International Journal of Industrial Ergonomics, 40(4), 437–447. Retrieved on November 15, 2022 from https://doi.org/10.1016/j.ergon.2010.02.002

Öztürk, N., & Esin, N. (2011). Investigation of Musculoskeletal Symptoms and Ergonomic Risk Factors Among Female Sewing Machine Operators in Turkey. International Journal of Industrial Ergonomics, 41(6), 585–591. Retrieved on January 19, 2023 from https://doi.org/10.1016/j.ergon.2011.07.001

Paper, C., & Aksaray, O. (2015). Finite Element Analysis (Fatigue) of Wooden Furniture Strength. Proceedings of the 27th International Conference, September, 335–342.

Paper, C., Altalmas, M., Ahmad, S., Akmeliawati, R., & Sidek, N. (2013). Mechanical Design and Simulation of Two-Wheeled Wheelchair Using Solidworks. May 2015. Retrieved on February 22, 2024 from https://doi.org/10.1088/1757-899X/53/1/012042

Parimalam, P., Kamalamma, N., & Ganguli, K. (2006). Ergonomic Interventions to Improve Work Environment in Garment Manufacturing Units. Indian Journal of Occupational and Environmental Medicine, 10(2), 74–77. Retrieved on July 21, 2023 from https://doi.org/10.4103/0019-5278.27304

Parsons, K. (1995). Ergonomics and international standards. Applied Ergonomics, 26(4), 237–238. Retrieved on October 23, 2022 from https://doi.org/10.1016/0003-6870(95)00039-F

Patil, G., Yadav, R., Nadiger, G., Raichurkar, P., Chandrakar, K., & Chandurkar, P. (2017). Textile Apparel Industry: A responsibilty Towards Manpower. Colourage, 64(6), 38–46.

Paul, P., Darius Gnanaraj, S., & Paul, S. (2019). Ergonomic Design and RULA Analysis of a Motorised Wheelchair For Disabled and Elderly. International Journal of Mechanical Engineering and Technology, 10(1), 1014–1025.

Pavlovic, S. (2013). Repetition as a Risk Factor For the Development of Musculoskeletal Disorders. Safety Engineering, 3, 39–45. Retrieved on Octoper 11, 2023 from https://doi.org/10.7562/SE2013.3.01.08

Pdd. (2014). Pugh Concept Selection Method. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=c0c101a8b0a225aa4e22127b4830abeaad1f768aabb4e3830aaea911514c317fJmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=pugh+concept+selection+method%2c+pdd12+2014.+pdf+download&u=a1aHR0cHM6Ly93d3cuc2NyaWJkLmNvbS9kb2N1bWVudC8zMzM1MjYwMDkvTU0x

Pentikis, J., Lopez, M., & Thomas, R. (2002). Ergonomics Evaluation of a Government Office Building. Work (Reading, Mass.), 18, 123–131.

Pereira, O., Schlosse, F., Souza d'Arisbo, D. de, Silva, S. de L., Opazo, U., Jandira de Sales, E., & Severino da Silva, S. (2014). Anthropometric Model and Obesity Index of Agricultural Tractor Operators. African Journal of Agricultural Research, 9(45), 3350–3359. Retrieved on December 09, 2022 from https://doi.org/10.5897/ajar2014.8948

Pessiot, F., Kim, M., Amini, R., & Gallinari, P. (2010). NRC Publications Archive (NPArC) Archives Des Publications Du CNRC (NPArC). Information Processing and Management, 46(2), 180–192.

Pickson, B., Bannerman, S., & Ahwireng, P. O. (2017). Investigating the Effect of Ergonomics on Employee Productivity: A Case Study of the Butchering and Trimming Line of Pioneer Food Cannery in Ghana. Modern Economy, 08(12), 1561–1574. Retrieved on October 17, 2023 from https://doi.org/10.4236/me.2017.812103

Planchard, D. (2018). Engineering Design with Solidworks 2019. 816–887. Retrieved on July 26, 2023 from https://en.my1lib.vip/book/5468018/ee2ba2

Planchard, C., & Planchard, P. (2006). Solidworks 2006 Tutorial Copyrighted Material Copyrighted Material Copyrighted Material Copyrighted Material.

Qaidir, M., & Abdillah, N. (2008). Design and Fabrication of Multi Purpose Ladder. November.

Rana, R., & Khanzode, V. (2020). Technology Enabled Ergonomic Design. Retrieved on September 18, 2022 from https://www.google.co.id/books/edition/Technology_Enabled_Ergonomic_Design/Th5iEAAAQBAJ?hl=id&gbpv=1

Ratnasingam, J. (2022). Furniture Manufacturing Systems (pp. 21–28). Retrieved on March 22, 2024 from https://doi.org/10.1007/978-981-16-9412-7_3

Ratnasingam, J., Ark, K., Latib, A., Subramaniam, H., & Khoo, A. (2019). Innovation in the Malaysian Furniture Industry: Drivers and Challenges. BioResources, 13(3), 5254–5270. Retrieved on March 03, 2023 from https://doi.org/10.15376/biores.13.3.5254-5270

Ratnasingam, J., Khoo, A., Jegathesan, N., Chee Wei, L., Ab Latib, H., Thanasegaran, G., Choon Liat, L., Yan Yi, L., Othman, K., & Amir, M. A. (2020). How are Small and Medium Enterprises in Malaysia's Furniture Industry Coping With Covid-19 pandemic? Early Evidences From a Survey and Recommendations For Policymakers. Bioresources, 15(3), 5951–5964. Retrieved on July 25, 2023 from https://doi.org/10.15376/biores.15.3.5951-5964

Ratnasingam, J., Ma, P., & Perkins, C. (1999). Productivity in Wood Machining Processes - a Question of Simple Economics? Holz Als Roh - Und Werkstoff, 57(1), 51–56. Retrieved on August 11, 2022 from https://doi.org/10.1007/PL00002621

Ratnasingam, J., & Scholz, F. (2004). Optimizing the Abrasive Sanding Process of Rubberwood (Hevea Brasiliensis). Holz Als Roh-Und Werkstoff, 62(6), 411–418. Retrieved on January 31, 2024 from https://doi.org/10.1007/s00107-004-0522-x

Ravindran, D. (2019). Ergonomic Impact on Employees' Work Performance. International Journal of Advance and Innovative Research, 6(1 (XI)), 231–236. Retrieved on November 10, 2022 from http://iaraedu.com/about-journal/ijair-volume-6-issue-1-xxxv-january-march-2019-part-2.php

Release, I. (2011). World Furniture Outlook 2010. 1–5. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=ed1e2838c80edde6f1b835b18253fedb5be7ad077d6f2aa223516eef7b405f55JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=World+Furniture+Outlook+2010.+pdf&u=a1aHR0cHM6Ly93d3cud29ybGRmdXJuaXR1cmVvbmxpbmUuY29tL1BERi9wcmVzcy1PdXRsb29rLTIwMTAucGRm

Research Papers Ergonomic Based Design and Survey of. (2014). 9(4), 27–31. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=ba24063427326e732cf7063095a45c3a298609119e56e9a38b402211cdc3fcb2JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=ERGONOMIC+BASED+DESIGN+AND+SURVEY+OF+ELEMENTARY+SCHOOL+FURNITURE%2c+2014.+pdf&u=a1aHR0cHM6Ly9maWxlcy5lcmljLmVkLmdvdi9mdWxsdGV4dC9FSjEwOTc2NjgucGRm

Rittel, A. (2010). Risk Con:trol The Graduate School University of Wisconsin-Stout April,2010. How to Overcome Resistance to Behavioral-Based Safety, 1–45.

Romli, I., & Aminian, O. (2018). Ergonomic Analysis of Aircraft Passenger Seat: A Malaysian Case Study. International Journal of Pure and Applied Mathematics, 119(15 Special Issue B), 3749–3754.

Rupasinghe, H., & Panuwatwanich, K. (2020). Extraction and Analysis of Construction Safety Hazard Factors From Open Data. IOP Conference Series: Materials Science and Engineering, 849(1). Retrieved on December 30, 2022 from https://doi.org/10.1088/1757-899X/849/1/012008

Saarni, L., Nygård, H., Kaukiainen, A., & Rimpelä, A. (2007). Are the Desks and Chairs at School Appropriate? Ergonomics, 50(10), 1561–1570. Retrieved on October 28, 2023 from https://doi.org/10.1080/00140130701587368

Safety, O., Substances, H., Toxicology, I., Hygiene, I., Safety, I., Measures, F., Sanitation, F., & Diseases, O. (2009). Occupational Safety and Health Thechnology Library Research Guide. 41(3).

Saguyod, V., Villapando, C., & Gumasing, J. (2021). An Ergonomic Workstation Design For Apparel Manufacturing Workers in the Philippines. Proceedings of the International Conference on Industrial Engineering and Operations Management, 2497–2504.

Sciences, A. (2014). Finite Element Modeling of Chair Frames Sandalye Çerçevelerinin Sonlu Elemanlar Analizi Finite element modeling of chair frames. January 2012.

Scott, A., & Erin Taylor, A. (2006). Ergonomics and Design A Reference Guide.

Allsteel Design to Work Build to Last, June 2006, 1–2. Retrieved on December 30, 2022 from www.allsteeloffi%5Cnce.com/ergo

Scurtu, L., Bodi, Ș, & Dragomir, M. (2015). Optimization Methods Applied in Energy-Efficient Building.Pdf. 58(January), 559–562.

Sealetsa, J., & Thatcher, A. (2011). Ergonomics issues among sewing machine operators in the textile manufacturing industry in Botswana. Work, 38(3), 279–289. Retrieved on May 20, 2023 from https://doi.org/10.3233/WOR-2011-1131

Sepehri, S., Habibi, H., & Shakerian, S. (2013). The Relationship Between Ergonomic Chair and Musculoskeletal Disorders in North of Khuzestan's Students. In Pelagia Research Library European Journal of Experimental Biology (Vol. 3, Issue 4). Retrieved on September 20, 2022 from www.pelagiaresearchlibrary.com

Shah, A., Amjad, A., Ashraf, M., Mushtaq, F., & Sheikh, I. A. (2016). Ergonomic Risk Factors For Workers in Garments Manufacturing - A Case Study From Pakistan. Proceedings of the International Conference on Industrial Engineering and Operations Management, 8-10 March, 2580–2584.

Sheba, P., Sheba, D., & Gnanaraj, S. (2009). Computer Aided Rapid Entire Body Assessment (CAREBA) Agent Based scheduling of Bag-of-Tasks Application in Cloud View Project S I-A-10 Ergonomics for Everyone International Ergonomics Conference Humanizing Work and Work Environment Computer Aided Rapid En. Retrieved on June 29, 2023 from https://www.researchgate.net/publication/338065614

Sheta, A., Abou-Ali, G., El-Gholmy, H., & Eladly, M. (2018). Anthropometric Body Measurements and the Ergonomic Design of the Sewing Machine Workstation. Textile Bioengineering and Informatics Symposium Proceedings 2018 - 11th Textile Bioengineering and Informatics Symposium, TBIS 2018, April, 519–524.

Silviana, Hardianto, A., & Hermawan, D. (2022). the Implementation of Anthropometric Measurement in Designing the Ergonomics Work Furniture. Eureka, Physics and Engineering, 2022(3), 20–27. Retrieved on September 23, 2023 from https://doi.org/10.21303/2461-4262.2022.001967

Simek, M., & Sebera, V. (2010). Traditional Furniture Joinery From the Point of View of Advanced Technologies. International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe, 1–9.

Simonsen, E., & Berlin, C. (2017). Ergonomics activities in the product development process. August, 224–231.

Soana, V., Minooee, S., Federico, S., & Helge, B. (2025). Elastic robotic structures : a multidisciplinary framework for the design and control of shape - morphing elastic system for architectural and design applications. Construction Robotics. Retrieved on Jaunary 31, 2025 from https://doi.org/10.1007/s41693-024-00128-8

Soewardi, H., Dila, A., & Rizkiningtias, P. (2016). Ii 23om. 177–180. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=efcbc22fbacc792ac2295162fefa1ddd8b991b437d634ae93fcbcfe4379133daJmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Development+of+Working+Environment+Comfort+to+Improve+Productivity+Hartomo%2c+2016.+pdf&u=a1aHR0cHM6Ly93d3cucmVzZWFyY2hnYXRlLm5ldC9wdWJsaWNhdGlvbi8zMTIwMzc5NDRfRGV2ZWxvcG1lbnRfb2Zfd29ya2luZ19lbnZpcm9ubWVudF9jb21mb3J0X3RvX2ltcHJvdmVfcHJvZHVjdGl2aXR5

Sohn, J., Nielsen, S., Birkved, M., Joanes, T., & Gwozdz, W. (2021). The Environmental Impacts of Clothing: Evidence From United States and Three European Countries. Sustainable Production and Consumption, 27, 2153–2164. Retrieved on October 28, 2022 from https://doi.org/10.1016/j.spc.2021.05.013

SolidWorks. (1995). Fundamentals of 3D Design and Simulation. Retrieved on April 21, 2024 from www.solidworks.com/edureseller.

SolidWorks. (2010). Series Student's Guide to Learning Solidworks Software. Dassault Systèmes A, 156. Retrieved on February 23, 2023 from http://www.solidworks.com/education

Staneva, N., Genchev, Y., & Hristodorova, D. (2018). Approach to Designing an Upholstered Furniture Frame by the Finite Element Method. Acta Facultatis Xylologiae, 60, 61–69. Retrieved on November 20, 2023 from https://doi.org/10.17423/afx.2018.60.2.06

Starovoytova, D. (2019). Innovative Engineering Product Design : Concepts and Practical Examples. June.

Starovoytova, D., Kiptoo, D., & Njuguna, M. (2016). Design simulation and analysis of manual block-making machine. 7(7). Retrieved on March 24, 2024 from www.iiste.org

Stokke, D. (2013). Introduction to Wood and Natural Fiber Composites. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=8e0e779fb62537c29c590eb1bcc68dd30f4697031fe76c825a0e5411e23a4a5fJmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Introduction+to+Wood+and+Natural+Fiber+Composites%2c+2013.+pdf&u=a1aHR0cHM6Ly9vbmxpbmVsaWJyYXJ5LndpbGV5LmNvbS9kb2kvYm9vay8xMC4xMDAyLzk3ODA0NzA3MTE4MDQ_bXNvY2tpZD0yOGFhYmVhZDIwNDI2MDUwMTE2N2FiMmIyMTdhNjE3YQ

Submitted, T., Partial, N., of, F., For, R., & Degree, E. (2015). A Thesis Submitted in Partial Fullfilment of the. April.

Sundelin, G., & Hagberg, M. (1989). The Effects of Different Pause Types on Neck and Shoulder Emg Activity During Vdu work. Ergonomics, 32(5), 527–537. Retrieved on October 27, 2023 from https://doi.org/10.1080/00140138908966123

Systemes, D. (2021). Solidworks Software. Solidworks, 9–11. Retrieved on June 21, 2023 from https://www.solidworks.com/es

Systèmes, D. (2020). Solidworks 2020. Retrieved on September 24, 2025 from https://www.bing.com/ck/a?!&&p=61e7697586d44cd123a5132796f1846f35d43e11f5dfb42f9b832fa34b2974b7JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=SOLIDWORKS+2020+Tutorial+%c2%ae+A+Step-by-Step+Project+Based+Approach+Utilizing+3D+Solid+Modeling.+pdf&u=a1aHR0cHM6Ly96LWxpYnJhcnkuc2svYm9vay8xMTE4MjUyOC82MTBkM2Yvc29saWR3b3Jrcy0yMDIwLXR1dG9yaWFsLWEtc3RlcGJ5c3RlcC1wcm9qZWN0LWJhc2VkLWFwcHJvYWNoLXV0aWxpemluZy0zZC1tb2RlbGluZy5odG1s

Taifa, W., & Desai, A. (2017). Anthropometric Measurements For Ergonomic Design of Students' Furniture in India. Engineering Science and Technology, an International Journal, 20(1), 232–239. Retrieved on December 16, 2022 from https://doi.org/10.1016/j.jestch.2016.08.004

Talapatra, S., & Mohsin, N. (2020). An Assessment of Hazards and Risks in the Sewing Section of the Readymade Garment Industry in Bangladesh. Proceedings of the International Conference on Industrial Engineering and Operations Management, 0(March), 3053–3062.

Tee, S., Low, E., Saim, H., Zakaria, W., Khialdin, M., Isa, H., Awad, I., & Soon, F. (2017). A Study on the Ergonomic Assessment in the Workplace. Aip Conference Proceedings, 1883(October). Retrieved on May 18, 2023 from https://doi.org/10.1063/1.5002052

The Mendeley Support Team, & Shih, R. (2010). Introduction to Finite Element Analysis Using Solidworks Simulation 2011. Mendeley Desktop, 451. Retrieved on February 21, 2024 from http://www.mendeley.com

Tien, B., Hyung, L., Kim, S., Ishizaki, K., Duc, N., Parinov, A., & Editors, K. (2021). Lecture Notes in Mechanical Engineering of the International Conference on Advanced Mechanical Engineering , Automation , and Sustainable Development 2021 (Vol. 2021). Springer International Publishing. Retrieved on July 29, 2023 from https://doi.org/10.1007/978-3-030-99666-6

Ulijaszek, S., & Komlos, J. (2010). From a History of Anthropometry to Anthropometric history. Human Variation: From the Laboratory to the Field, 183–197. Retrieved on October 17, 2022 from https://doi.org/10.1201/9781420084740

Ullman, D. (2018). The Mechanical Design Process. Retrieved on September 20, 2025 from https://www.bing.com/ck/a?!&&p=f4117dccb9f124dd10e6d58cc087ca925e561631c26e92c35f62cd8168df4164JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=The+Mechanical+Design+Process%2c+2018.+pdf&u=a1aHR0cHM6Ly93d3cucmVzZWFyY2hnYXRlLm5ldC9wdWJsaWNhdGlvbi8yMzU3MDA4MTVfVGhlX01lY2hhbmljYWxfRGVzaWduX1Byb2Nlc3M

Upasana, & Vinay, D. (2017). Work Posture Assessment of Tailors By RULA and REBA Analysis. International Journal of Science, Environment and Technology, 6(4), 2469–2474. Retrieved on October 02, 2023 from http://www.ijset.net/journal/1849.pdf

Wang, M., & Chen, Y. (2012). Ergonomics in the Workplace in the Ergonomics in the. Proceedings - 3rd International Conference on Information Security and Intelligent Control, ISIC 2012, 186–189.

Wang, Y., Wang, J., Yeh, Y., Shih, C., & Lin, C. (1999). Development of Anthropometric Work Environment For Taiwanese Workers. International Journal of Industrial Ergonomics, 23(1–2), 3–8. Retrieved on November 30, 2023 from https://doi.org/10.1016/S0169-8141(97)00095-4

Wang, C., Harrison, J., Yu, F., Rempel, M., & Ritz, R. (2010). Follow-up of Neck and Shoulder Pain Among Sewing Machine Operators: The Los Angeles garment study. American Journal of Industrial Medicine, 53(4), 352–360. Retrieved on July 20, 2023 from https://doi.org/10.1002/ajim.20790

Westgaard, H., & Aarås, A. (1984). Postural Muscle Strain as a Causal Factor in the Development of Musculoskeletal Illnesses. Applied Ergonomics, 15(3), 162–174. Retrieved on October 27, 2022 from https://doi.org/10.1016/0003-6870(84)90057-7

Wibowo, H., & Mawadati, A. (2021). The Analysis of Employees' Work Posture by Using Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA). IOP Conference Series: Earth and Environmental Science, 704(1). Retrieved on June 21, 2023 from https://doi.org/10.1088/1755-1315/704/1/012022

Wiley, J. (2004). Kodak ' s Ergonomic Design for. Retrieved on September 15, 2025 from https://www.bing.com/ck/a?!&&p=ce55bfc249d340323ee43503b03d4668778b381fa454d0b96ece1f459f10c360JmltdHM9MTc1ODY3MjAwMA&ptn=3&ver=2&hsh=4&fclid=28aabead-2042-6050-1167-ab2b217a617a&psq=Kodak%e2%80%99s+People+at+Work+Design+for+Ergonomic+Second+Edition%2c+2004.+pdf&u=a1aHR0cHM6Ly9hcHAua25vdmVsLmNvbS93ZWIvcG9ydGFsL2Jhc2ljX3NlYXJjaC9kaXNwbGF5P19FWFRfS05PVkVMX0RJU1BMQVlfYm9va2lkPTE0MTM

Williams, L., Torrens, E., & Hodgson, R. (2004). Integration of Anthropometric Data Within a Computer Aided Design Model. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 218(10), 1417–1421. Retrieved on October 12, 2022 from https://doi.org/10.1243/0954405042323450

Woo, C., White, P., & Lai, K. (2016). Ergonomics Standards and Guidelines for Computer Workstation Design and the Impact on Users' Health – A Review. Ergonomics, 59(3), 464–475. Retrieved on September 24, 2022 from https://doi.org/10.1080/00140139.2015.1076528

Xiao, A., Park, S., & Freiheit, T. (2011). A Comparison of Concept Selection in Concept Scoring and Axiomatic Design Methods. Proceedings of the Canadian Engineering Education Association (CEEA). Retrieved on December 02, 2023 from https://doi.org/10.24908/pceea.v0i0.3769

Xiong, X., Guo, W., Fang, L., Zhang, M., Wu, Z., Lu, R., & Miyakoshi, T. (2017). Current State and Development Trend of Chinese furniture industry. Journal of Wood Science, 63. Retrieved on May 13, 2023 from https://doi.org/10.1007/s10086-017-1643-2

Xu, W., Wu, Z., & Zhang, J. (2015). Compressive Creep and Recovery Behaviors of Seat Cushions in Upholstered Furniture. Wood and Fiber Science: Journal of the Society of Wood Science and Technology, 47, 431–444.

Yale & Safety. (2018). Ergonomics: Awkward Posture. Yale Environment Health & Safety, 1. Retrieved on October 29, 2022 from https://ehs.yale.edu/sites/default/files/files/ergo-awkward-posture.pdf

Yang, Y., & Zhong, C. (1998). China's Textile and Clothing Exports in a Changing World Economy. Developing Economies, 36(1), 19–22. Retrieved on July 20, 2023 from https://doi.org/10.1111/j.1746-1049.1998.tb00858.x

Yao, A., & Carlson, J. (2003). Agility and Mixed-Model Furniture Production. International Journal of Production Economics, 81, 95–102. Retrieved on August 04, 2023 from https://doi.org/10.1016/S0925-5273(02)00359-6

Ye, Z., Li, X., & Li, Y. (2013). The Virtual Prototyping Design and Evaluation of Ergonomic Gymnastic Based on CATIA. International Journal of Hybrid Information Technology, 6(5), 67–78. Retrieved on October 21, 2023 from https://doi.org/10.14257/ijhit.2013.6.5.07

Young, S. (2009). Kodak's Ergonomic Design for People at Work. Ergonomics, 52(6), 756–757. Retrieved on June 23, 2023 from https://doi.org/10.1080/00140130902924147

Zeynep, D., Nejdiye, M., & Meral, T. (2019). The Prevalence of Work-Related Muskuloskeletal Disorders (WRMSDs) and Related Factors Among Occupational Disease Clinic Patients. International Archives of Public Health and Community Medicine, 3(2). Retrieved on December 29, 2022 from https://doi.org/10.23937/2643-4512/1710030

Zhang, B., & Zhang, B. (2005a). Using Artifi Cial Neural Networks For the Transformation of Human Body Postures Based on Landmarks Door.

Zhang, B., & Zhang, B. (2005b). Using Artifi Cial Neural Networks For the Transformation of Human Body Postures Based on Landmarks Door.

Zhao, C., & Li, J. (2014). Analysis and Improvement of Multi-Product Assembly Systems: An Application Study at a Furniture Manufacturing Plant. International Journal of Production Research, 52(21), 6399–6413. Retrieved on April 23, 2023 from https://doi.org/10.1080/00207543.2014.948576

Zhao, H., Wang, J., Yufei, M., Li, Z., Fei, B., Das, M., & Jiang, Z. (2022). Bamboo and Rattan: Nature-Based Solutions For Sustainable Development. The Innovation, 3, 100337. Retrieved on January 08, 2023 from https://doi.org/10.1016/j.xinn.2022.100337

APPENDICES

Appendix I: Research Area Map

Source: *(mapsworld.com).*

Appendix II: Some ISO Standards for Ergonomists

Standard	Year published	Title
General:		
-ISO 7317	1987	Ergonomics: Standards guidelines for designers.
-ISO 6385	1981	Ergonomics principles in the design of work-systems.
-ISO 18529	2000	Ergonomics-Ergonomics of human system interaction-human-centered lifecycle process descriptions.
-ISO 13407	1999	Human-centered design processes for interactive systems.
Physical-workload:		
-ISO 1128-1-3	2000	Ergonomics-manual handling parts 1 to 3
-ISO 53120	1996	Equipment for manual handling.
-ISO 11226	2000	Ergonomics-evaluation of static work postures.
Workspace design:		
-ISO 9241	1990s	Ergonomics requirements for office work with visual display terminals-parts 1-9.
-ISO 11064-1	-	Ergonomic design of control centers. Control room layout.
Physical environment:		
-ISO 13340-1	1995	Protective equipment in general.
-ISO 1996	1996	Protective gloves.
Physical work/stress:		
-ISO 8996	1990	Ergonomics-determination of metabolic heat production.
Mental work/HCI:		
-ISO 9241	1990s	Ergonomic requirements for office work with visual display terminals-parts 1017.

Display and controls:		
-ISO 9355	1999	Ergonomic principles for the design of signals.
-ISO 11429	1996	Ergonomics-system of auditory and visual danger and information signals.
-ISO 7731	1986	Ergonomics. Danger signals for public and work areas auditory danger signals.
Work environment:		
-ISO 13731	1995	Ergonomics of the thermal environment. Vocabulary and symbols.
-ISO 11399	2001	Ergonomics of the thermal environment-principles and application of relevant international standards.
-ISO 9116-1	1989	Lighting in general.
-ISO 91160-10	1989	Interior lighting.
-ISO 8995	1989	Principles of visual ergonomics-the lighting of indoor work systems.
-ISO 1996-1	1982	Acoustics-description and measurement of environment noise.
-ISO 9921-1	1996	Ergonomic assessment of speech communication.
Safety:		
-ISO 15534-1-3	2000	Ergonomic design for the safety of machinery, parts 1-3.
-ISO 14121	1999	Safety of machinery-principles of risk assessment.
-ISO 13854	1996	Safety of machinery-minimum gaps to avoid crushing parts of the human body.

Source: *(Woo et al., 2016 and Parsons, 1995)*

Appendix III: ISO 7250-1 International Standard

Contents

Page

Basic human body measurements for technological design —

Part 1: Body measurement definitions and landmarks

1 Scope

This document provides a description of anthropometric measurements which can be used as a basis for comparison of population groups and for the creation of anthropometric databases (see ISO 15535). The basic list of measurements specified in this document is intended to serve as a guide for ergonomists who are required to define population groups and apply their knowledge to the geometric design of the places where people work and live. In addition, the list serves as a basis for extracting one- and two-dimensional measurements from three-dimensional scans (specified in ISO 20685). It serves as a guide on how to take anthropometric measurements, but also gives information to the ergonomist and designer on the anatomical and anthropometrical bases and principles of measurement which are applied in the solution of design tasks.

This document is intended to be used in conjunction with national or international regulations or agreements to ensure harmony in defining population groups and to allow comparison of anthropometric data among member bodies. In its various applications, it is anticipated that the basic list will be supplemented by specific additional measurements. Annex A shows the correspondence of dimensions described here with their use in ISO 14738 and ISO 15534.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
population group
group of people having some common environment or activity

Note 1 to entry: These groups may be as diverse as geographically defined populations or specified age groups.

3.2
anterior
ventral
towards the front of the body

6.2 Measurements taken while the subject sits

6.2.1 Sitting height (erect)

Description: Vertical distance from a horizontal sitting surface to the highest point of the head (vertex). See Figure 33.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. The head is oriented in the Frankfurt plane.

Instrument: Anthropometer.

Figure 33 — Sitting height (erect)

6.2.2 Eye height, sitting

Description: Vertical distance from a horizontal sitting surface to the outer corner of the eye (ectocanthus). See Figure 34.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. Head is oriented in the Frankfurt plane.

Instrument: Anthropometer.

Figure 34 — Eye height, sitting

6.2.3 Cervicale height, sitting

Description: Vertical distance from a horizontal sitting surface to the cervicale. See Figure 35.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. Head is oriented in the Frankfurt plane.

Instrument: Anthropometer.

Figure 35 — Cervicale height, sitting

6.2.4 Shoulder height, sitting

Description: Vertical distance from a horizontal sitting surface to the acromion. See Figure 36.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. Shoulders are relaxed, with upper arms hanging freely.

Instrument: Anthropometer.

Figure 36 — Shoulder height, sitting

6.2.5 Elbow height, sitting

Description: Vertical distance from a horizontal sitting surface to the lowest bony point of the elbow bent at a right angle with the forearm horizontal. See Figure 37.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. Upper arms hang freely downwards and forearms are horizontal.

Instrument: Anthropometer.

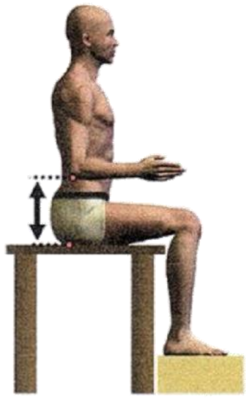


Figure 37 — Elbow height, sitting

6.2.10 Hip breadth, sitting

Description: Breadth of the body measured across the widest portion of the hips. See Figure 42.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal, but the feet and knees are together. Measurement is taken without pressing into the flesh of the hips.

Instrument: Large sliding caliper.

Figure 42 — Hip breadth, sitting

6.2.11 Popliteal height, sitting

Description: Vertical distance from the foot-rest surface to the lower surface of the thigh immediately behind the knee, bent at right angles. See Figure 43.

Method: Subject sits with the foot placed on a raised platform so the thigh and lower leg are at right angles during measurement. The movable arm of the measuring instrument is pushed gently against the tendon of the relaxed biceps femoris muscle.

Instrument: Anthropometer.

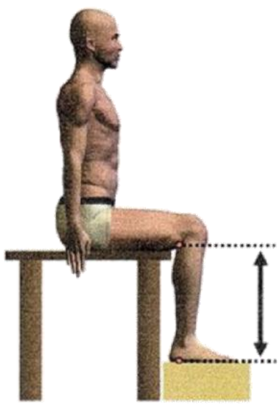


Figure 43 — Popliteal height, sitting

6.2.12 Thigh clearance

Description: Vertical distance from the sitting surface to the highest point on the thigh. See Figure 44.

Method: Subject sits erect with knees bent at right angles, supporting the feet flat on the floor.

Instrument: Anthropometer.

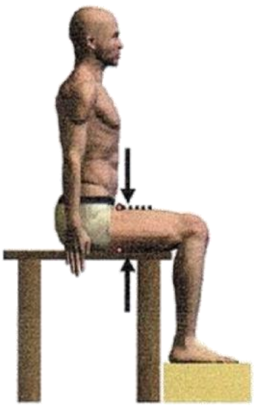


Figure 44 — Thigh clearance

6.2.13 Knee height, sitting

Description: Vertical distance from the floor to the highest point of the superior border of the patella (suprapatella, sitting). See Figure 45.

Method: Subject sits erect with knees bent at right angles, supporting the feet flat on the floor.

Instrument: Anthropometer.

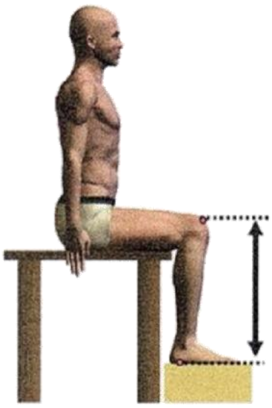


Figure 45 — Knee height

6.4.6 Forearm-fingertip length

Description: Horizontal distance from olecranon (back of the elbow) to the tip of the middle finger, with the elbow bent at right angles. See Figure 74.

Method: Subject sits or stands erect with the upper arm hanging downwards, the forearm horizontal and the hand extended.

Instrument: Large sliding caliper.

Figure 74 — Forearm-fingertip length

6.4.7 Buttock-popliteal length (seat depth)

Description: Horizontal distance from the hollow of the knee to the rearmost point of the buttock. See Figure 75.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other and the sitting surface extending as far as possible into the hollow of the knee. The position of the rearmost point of the buttock is vertically projected onto the sitting surface by means of a measuring cube which touches the buttocks. Distance is measured from the measuring block to the forward edge of the sitting surface.

Instrument: Anthropometer, measuring cube.

Figure 75 — Buttock-popliteal length (seat depth)

6.4.8 Buttock-knee length

Description: Horizontal distance from the foremost point of the knee-cap to the rearmost point of the buttock. See Figure 76.

Method: Subject sits fully erect with the feet supported so that the femora are horizontal and parallel to each other. The position of the rearmost point of the buttock is vertically projected onto the sitting surface by means of a measuring block which touches the buttocks. Distance is measured from the measuring cube to the foremost point of the knee-cap.

Instrument: Anthropometer, measuring cube.

Figure 76 — Buttock-knee length

6.4.9 Neck circumference

Description: Circumference of the neck at a point just below the bulge at the thyroid cartilage, perpendicular to the long axis of the neck. See Figure 77.

Method: Subject sits or stands erect with the head in the Frankfurt plane.

Instrument: Tape measure.

Figure 77 — Neck circumference

Annex A
(informative)

Correspondence between ISO 7250-1 dimension names and numbers and ISO 14738 and ISO 15534 anthropometric dimension codes

See Table A.1.

Table A.1 — Names, numbers and codes for anthropometric dimensions

ISO 7250-1		ISO 14738 code	ISO 15534 code
Number/Subclause	Dimension name		
6.1.1	Body mass (weight)		
6.1.2	Stature (body height)	h_1	h_1
6.1.3	Eye height		
6.1.4	Shoulder height		
6.1.5	Elbow height	h_4	
6.1.6	Iliac spine height, standing		
6.1.7	Crotch height	h_6	
6.1.8	Tibial height		
6.1.9	Chest depth, standing		
6.1.10	Body depth, standing		b_1
6.1.11	Chest breadth, standing		
6.1.12	Hip breadth, standing		
6.2.1	Sitting height (erect)	h_{11}	
6.2.2	Eye height, sitting	h_{12}	
6.2.3	Cervicale height, sitting		
6.2.4	Shoulder height, sitting	h_{13}	
6.2.5	Elbow height, sitting		
6.2.6	Shoulder-elbow length		
6.2.7	Shoulder (biacromial) breadth	a_2	
6.2.8	Shoulder (bideltoid) breadth		
6.2.9	Elbow-to-elbow breadth		a_1
6.2.10	Hip breadth, sitting	a_{17}	
6.2.11	Popliteal height, sitting	h_{16}	
6.2.12	Thigh clearance	b_{18}	
6.2.13	Knee height, sitting		
6.2.14	Abdominal depth, sitting		
6.2.15	Thorax depth at the nipple		
6.2.16	Buttock-abdomen depth, sitting	b_{15}	
6.3.1	Hand length		t_4
6.3.2	Palm length		
6.3.3	Hand breadth at metacarpals		a_4

Table A.1 *(continued)*

ISO 7250-1		ISO 14738 code	ISO 15534 code
Number/Subclause	Dimension name		
6.3.4	Index finger length		t_6
6.3.5	Index finger breadth, proximal		a_5
6.3.6	Index finger breadth, distal		
6.3.7	Foot length	c_2	c_2
6.3.8	Foot breadth		a_6
6.3.9	Head length		
6.3.10	Head breadth		
6.3.11	Face length (menton-sellion)		
6.3.12	Head circumference		
6.3.13	Sagittal arc		
6.3.14	Bitragion arc		
6.3.15	Thumb length		
6.3.16	Thumb breadth		
6.3.17	Hand thickness		b_3
6.3.18	Hand breadth including thumb		a_3
6.3.19	Arm circumference flexed		d_1
6.3.20	Forearm circumference flexed		
6.4.1	Wall-acromion distance		
6.4.2	Grip reach; forward reach	b_2	b_2
6.4.3	Elbow-wrist length		
6.4.4	Elbow-grip length		
6.4.5	Fist (grip axis) height		
6.4.6	Forearm-fingertip length		
6.4.7	Buttock-popliteal length (seat depth)		
6.4.8	Buttock-knee length	c_1	c_1
6.4.9	Neck circumference		
6.4.10	Chest circumference		
6.4.11	Waist circumference		
6.4.12	Wrist circumference		
6.4.13	Thigh circumference		
6.4.14	Calf circumference		

Appendix IV: Introductory Letter

MOI UNIVERSITY
SCHOOL OF ENGINEERING
DEPARTMENT OF MANUFACTURING, INDUSTRIAL AND TEXTILE ENGINEERING

Telephone:(+254(0)790940508 **Ext.** 2795
(+254(0)736138770
E-mail: hodmit@mu.ac.ke

School of Engineering
P. O. Box 3900
Eldoret, **KENYA**

Our Ref: MU/DMIT/SP/002 **DATE:** 24th May, 2023

Managing Director
Rivatex East Africa Limited
P.O Box 4744
ELDORET

Dear Sir/Madam,

SUBJECT: ABDALLA ELNOUR AHMED ESMAEEL– PHD/IE/5675/22

The above named person is a Postgraduate student of Moi University, School of Engineering, Department of Manufacturing, Industrial and Textile Engineering. He is enrolled in a three year PhD program in Industrial Engineering.

He is doing a research on *"Integration of Anthropometric data in the Ergonomic Design of sewing workstation in Garment Manufacturing"*.

Any assistance accorded to him is highly appreciated.

CHAIRMAN
DEPARTMENT OF MANUFACTURING,
INDUSTRIAL AND TEXTILE ENGINEERING,
MOI UNIVERSITY

Dr. David Njuguna Githinji
Chair, Department of Manufacturing, Industrial & Textile Engineering

DNG/rk

(ISO 9001:2015 Certified Institution)

Appendix V: Research Authorization

MOI UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF MANUFACTURING, INDUSTRIAL AND TEXTILE ENGINEERING

Telephone:(+254(0)790940508 **Ext.** 2795
(+254(0)736138770
E-mail: *hodmit@mu.ac.ke*

School of Engineering
P. O. Box 3900
Eldoret, **KENYA**

Our Ref: **MU/DMIT/SP/002**

DATE: 24th May, 2023

Managing Director
Rivatex East Africa Limited
P.O Box 4744
ELDORET

Dear Sir/Madam,

SUBJECT: **ABDALLA ELNOUR AHMED ESMAEEL– PHD/IE/5675/22**

The above named person is a Postgraduate student of Moi University, School of Engineering, Department of Manufacturing, Industrial and Textile Engineering. He is enrolled in a three year PhD program in Industrial Engineering.

He is doing a research on "*Integration of Anthropometric data in the Ergonomic Design of sewing workstation in Garment Manufacturing*".

RIVATEX E.A. LTD.
P.O. Box 4744 - 30100, ELDORET
RECEIVED
(HRD DEPT)

Any assistance accorded to him is highly appreciated.

CHAIRMAN
DEPARTMENT OF MANUFACTURING,
INDUSTRIAL AND TEXTILE ENGINEERING,
MOI UNIVERSITY

Dr. David Njuguna Githinji
Chair, Department of Manufacturing, Industrial & Textile Engineering

DNG/rk

(ISO 9001:2015 Certified Institution)

Appendix VI: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **773814**

Date of Issue: **11/September/2023**

RESEARCH LICENSE

This is to Certify that Mr.. Abdalla ESMAEEL of Moi University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Uasin-Gishu on the topic: INTEGRATION OF ANTHROPOMETRIC DATA IN THE ERGONOMIC DESIGN OF SEWING WORKSTATION FOR GARMENTS MANUFACTURING. CASE STUDY AT RIVATEX EAST AFRICA LIMITED ELDORET, KENYA. for the period ending : 11/September/2024.

License No: **NACOSTI/P/23/27277**

773814

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix VII: Basic Workers Body Dimensions and Their Importance

Basic workers body dimensions	Importance	Critical
Eye height	Eye height is important for TV height in house, blackboard for study-room or in school, soft board, etc.	If TV height is not-according to the eye-height of human than person will not feel comfortable while watching TV in-sitting-posture
Shoulder height	Shoulder-height is important for designing backrest of chair	If backrest of your chair is not according to the shoulder height than to use that chair is not-comfortable for user.
Elbow height	Elbow height is important for designing a-height of arm rest in chair & table (study table, Dining table, etc.).	If height of arm rest is not according to the elbow height, it will give pain to the user's hand.
Knee height	Knee height is important for designing a-sitting height of the-chair.	If sitting height of chair is not according to the knee height, then your legs will hang without any support & will pain in your legs.
Buttock popliteal length	Buttock to popliteal-length is important for designing depth of the chair.	If depth of the chair is not according to this, user will not feel comfortable.
Popliteal height	Popliteal height is important for designing chair & WC sitting-height, bed height, stool-height, etc.	If the height of WC pan is not according to the popliteal height then person will not feel-comfortable while using it.
Hip breadth	Hip breadth is important to design a breadth of chair.	Person will not feel Comfortable if the breadth of chair sitting is not according to the hip-breadth.
Forearm hand length	Forearm hand length is important for designing width of study table, working table, dining table, etc.	If the distance between chair & table is not according to the forearm hand length then person will not feel comfortable while working, writing, or eating.

Source: *(Baharampour et al., 2013)*

Appendix VIII: Anthropometric Data Collection Form

Department of Manufacturing Industrial and Textile Engineering,

School of Engineering,

Moi University, Eldoret, Kenya

Worker's anthropometric data	
Data No.	
Sex	
Department	Sewing

No.	**Anthropometric data**	**Unit/cm**
1.	Sitting height (erect)	
2.	Shoulder height sitting	
3.	Popliteal height, sitting	
4.	Elbow height, sitting	
5.	Buttock popliteal length (seat death)	
6.	Buttock knee length	
7.	Thigh clearance	
8.	Eye height, sitting	
9.	Knee height sitting	
10.	Forearm fingertip length	
11.	Hip breadth sitting	

Appendix IX: Standard Normal Table

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

Source: (Anonymous, 2021)**.**

Appendix X: Sewing workstation furniture dimensions' form

Department of manufacturing industrial and textile engineering,

School of engineering,

Moi University, Eldoret, Kenya

No	Abbreviations	Dimensions of sewing workstation furniture	Unit/cm
1.	TW	Table width	
2.	TD	Table depth	
3.	TH	Table height	
4.	BH	Backrest height	
5.	SW	Seat width	
6.	SD	Seat depth	
7.	SH	Seat height	
8.	LSH	Lumber support height	

Appendix XI: Anthropometric Data Record For Workers from REAL (n = 100)

S. No	SH	SHS	PHS	EHS	BPL	BKL	TC	EHS	KHS	FFL	HBS
1	81.80	55.00	47.40	19.50	47.10	59.40	11.60	69.10	51.00	43.85	35.55
2	82.50	54.70	46.00	16.70	54.00	64.50	12.20	71.00	54.00	49.98	31.43
3	81.30	53.50	46.00	18.20	55.30	64.30	15.10	67.90	52.20	46.72	36.45
4	80.80	52.40	44.90	14.00	51.50	62.30	09.00	69.30	49.70	47.88	33.16
5	86.90	58.70	45.50	22.30	52.70	64.40	11.00	74.00	51.00	48.11	36.15
6	89.10	60.30	49.50	18.50	56.10	67.00	13.70	75.70	56.20	49.46	36.85
7	83.00	57.00	44.90	24.40	51.00	59.70	13.80	71.50	50.20	44.49	34.04
8	82.00	53.50	45.00	13.70	49.20	57.10	11.90	69.30	48.20	43.48	29.18
9	83.50	55.60	46.20	19.40	49.70	60.50	14.00	73.30	51.10	46.97	29.92
10	85.10	54.20	43.10	14.90	51.50	61.80	15.70	72.40	49.40	49.37	31.79
11	81.00	56.80	47.10	18.90	51.10	60.30	12.40	70.30	49.40	47.39	32.32
12	85.10	55.60	44.50	18.70	52.20	61.50	12.10	72.00	50.50	45.97	31.13
13	83.20	52.10	46.30	22.20	50.60	61.60	11.30	70.70	54.90	48.84	33.48
14	81.70	53.40	49.30	13.30	60.50	71.40	10.30	72.50	59.40	52.86	32.71
15	79.80	57.40	46.90	16.60	52.20	62.00	08.80	70.00	51.00	47.23	31.53
16	81.30	52.50	45.60	18.50	49.40	59.10	10.10	70.60	49.80	47.87	34.84
17	81.10	57.10	45.90	14.80	53.50	63.10	15.30	72.10	52.70	49.15	36.62
18	84.10	58.60	46.00	18.40	51.00	59.80	10.30	71.50	51.70	47.24	31.96
19	81.90	54.70	47.30	13.40	54.00	63.20	10.10	67.30	52.80	44.26	30.92
20	87.20	59.30	52.80	12.80	58.30	69.10	09.80	75.50	60.60	51.77	34.83
21	83.10	58.00	52.30	17.20	56.70	67.90	09.00	73.20	57.90	50.05	32.27
22	80.60	56.00	47.20	17.90	52.90	62.30	13.70	72.40	53.60	47.53	31.36
23	79.50	53.50	43.70	15.10	49.30	59.00	10.40	71.10	50.60	46.35	39.09
24	86.00	60.70	51.50	16.40	54.10	63.30	11.60	75.50	58.60	53.41	36.47
25	79.20	53.30	42.10	17.10	56.00	60.10	10.20	68.60	48.00	46.57	34.02
26	84.20	55.30	44.00	19.90	50.20	63.80	15.57	70.70	48.70	46.20	40.10
27	77.20	52.20	43.30	17.50	48.30	60.50	10.00	68.40	49.60	46.67	33.94
28	76.60	51.00	44.60	17.30	46.50	58.40	11.50	64.90	50.00	44.42	34.06
29	77.00	52.65	41.20	19.80	45.90	57.70	15.00	66.20	49.00	42.00	37.67
30	78.40	56.10	40.50	17.50	53.60	63.00	12.30	67.40	53.60	48.85	34.83
31	83.00	56.80	42.80	23.60	50.00	65.50	18.20	68.20	53.90	46.97	40.99
32	81.00	54.10	41.20	18.40	53.00	64.10	14.70	69.60	51.60	45.56	37.79
33	79.00	52.80	42.50	14.80	48.00	58.40	12.00	67.50	47.00	43.27	35.22
34	77.00	53.20	43.90	16.80	50.00	60.20	09.50	67.00	48.20	44.00	37.32
35	77.30	55.30	41.50	16.80	51.50	61.30	11.20	66.50	48.50	43.81	39.34
36	72.50	52.00	43.10	17.00	49.20	58.30	11.30	64.20	47.40	42.36	34.43
37	76.00	51.40	41.70	19.90	50.10	60.10	13.10	63.40	48.00	42.80	34.21
38	77.50	49.50	43.30	20.00	48.00	58.50	16.10	63.00	46.00	43.06	38.79
39	80.80	55.90	46.60	17.60	56.40	65.40	18.60	69.20	55.00	48.17	35.47
40	81.20	55.00	42.80	20.60	42.00	57.40	11.00	68.00	48.00	45.29	35.51
41	78.00	55.00	45.30	17.60	54.80	64.60	14.50	66.70	52.90	46.23	32.98
42	79.20	53.40	43.70	20.00	52.00	60.50	08.60	68.00	47.20	45.73	33.98
43	78.90	51.80	46.50	18.60	50.00	62.30	14.90	65.90	51.00	47.98	35.85
44	77.90	52.50	42.00	17.50	50.30	60.20	12.40	66.30	48.00	41.65	40.92
45	75.80	52.40	44.60	16.80	51.00	62.20	15.00	65.00	49.50	45.28	37.49
46	80.00	58.00	45.00	27.50	51.00	61.50	16.50	70.00	49.00	45.53	37.70
47	94.30	56.70	48.00	16.60	52.00	61.70	16.20	74.00	53.00	50.32	34.63
48	83.00	54.20	48.00	24.10	56.00	64.40	14.50	70.50	55.00	46.02	36.76
49	80.00	55.20	46.00	21.20	51.70	61.50	15.00	69.10	51.00	47.31	34.90
50	80.00	56.00	45.50	18.00	53.00	63.60	18.00	69.20	52.70	45.72	36.13
51	83.20	54.10	45.70	20.70	54.60	63.30	10.90	70.00	52.90	46.15	33.73
52	78.60	52.60	41.90	18.70	51.60	61.20	11.50	71.70	48.10	46.61	40.75
53	77.10	50.50	45.50	11.80	53.30	62.40	11.00	66.60	50.30	46.48	33.29
54	86.50	58.30	45.60	18.50	54.20	65.20	19.30	73.30	55.30	48.89	43.76
55	77.60	51.10	42.60	18.20	49.20	58.80	12.60	66.70	49.60	44.65	39.31
56	83.70	57.10	45.20	21.20	53.50	63.30	10.50	70.00	51.40	47.09	35.62
57	70.80	47.10	40.60	19.10	44.80	54.60	08.40	59.80	45.80	42.67	33.44
58	79.30	55.60	45.20	20.30	59.00	67.70	15.00	68.10	54.70	48.74	40.50
59	76.40	55.00	42.20	19.50	52.20	58.00	13.70	67.20	49.10	45.72	33.44
60	75.40	49.20	43.60	13.20	53.80	64.30	10.70	65.70	51.10	44.89	34.52
61	77.60	50.20	43.80	11.20	52.80	62.20	08.30	65.60	51.70	74.99	30.49
62	79.30	52.30	41.90	17.30	47.50	56.30	16.90	67.90	48.70	43.58	37.37
63	80.90	52.10	41.50	14.50	52.50	63.30	11.10	68.20	49.70	45.59	36.45
64	78.70	52.80	44.10	13.50	54.00	63.10	15.90	65.30	51.80	46.75	35.66
65	83.80	56.50	43.90	15.40	51.60	60.90	10.30	69.40	49.40	44.78	31.73
66	74.30	50.60	42.50	13.30	48.20	58.20	13.30	63.80	48.80	43.60	33.56
67	80.10	52.10	45.20	16.50	53.80	60.90	16.20	67.20	51.50	46.19	37.93
68	82.90	51.80	41.20	18.40	49.50	57.50	14.10	68.00	48.50	44.51	35.51
69	83.20	55.60	44.50	13.80	55.30	66.20	14.10	70.90	52.20	49.09	34.77
70	73.50	48.70	43.20	11.40	50.60	58.30	09.90	62.70	48.90	42.28	34.93
71	80.50	55.00	44.40	15.00	52.20	60.20	11.10	69.70	55.00	45.88	34.47
72	79.20	51.20	42.30	16.60	49.20	59.10	13.20	70.80	49.40	43.99	38.25
73	79.50	54.50	42.20	21.50	48.80	55.50	11.20	66.90	48.60	43.26	35.77
74	80.20	52.20	43.40	13.40	51.50	62.30	11.70	69.40	51.20	44.29	36.79
75	76.80	51.40	42.30	19.60	47.30	56.10	10.60	68.30	49.10	42.90	36.92
76	81.10	53.40	46.10	21.40	51.50	60.50	09.70	69.00	53.10	45.71	31.18
77	80.20	54.00	42.10	21.90	48.20	56.30	15.10	67.00	50.50	43.34	34.14
78	87.40	54.70	43.50	14.80	50.40	59.70	14.90	66.70	49.80	43.10	35.27
79	77.10	55.30	43.90	17.80	47.80	59.30	15.50	69.30	49.10	44.60	36.57
80	76.20	49.50	41.80	16.30	50.30	59.20	10.90	65.30	49.90	42.69	34.71
81	75.90	52.30	41.80	14.30	49.30	58.10	12.10	66.30	50.20	43.31	36.97
82	80.10	53.50	42.00	15.80	50.00	60.20	15.70	69.00	51.10	44.01	37.41
83	79.60	54.90	41.60	14.70	49.70	59.20	09.30	67.10	47.20	44.47	33.87
84	87.30	55.70	43.30	21.30	51.10	62.10	13.50	68.60	50.40	45.21	43.25
85	77.30	54.80	40.20	22.40	45.20	56.40	14.50	69.00	47.20	37.99	40.95
86	71.60	47.90	40.30	17.80	45.40	54.10	09.40	66.20	46.60	40.06	35.07
87	76.40	53.10	43.30	13.30	49.70	60.20	14.70	64.90	49.60	41.78	37.89
88	80.10	54.60	45.60	16.30	52.10	62.30	11.20	68.90	53.70	45.26	38.79
89	81.30	57.10	43.70	16.10	53.70	62.70	08.40	70.60	49.50	46.19	34.67
90	78.50	52.70	42.90	15.30	52.60	61.20	11.20	66.10	50.80	42.28	35.93
91	80.80	57.00	41.20	17.70	50.00	60.20	11.30	68.60	48.60	45.76	38.07
92	78.80	50.90	43.90	18.80	48.30	57.00	16.60	68.20	47.20	44.35	35.53
93	80.80	60.50	42.90	20.70	53.00	64.50	15.20	71.30	50.00	46.97	46.41
94	78.90	54.70	42.00	16.80	49.40	60.20	16.20	68.40	50.70	46.61	42.10
95	81.70	57.00	44.60	18.20	51.40	61.80	14.60	68.50	50.40	46.57	38.92
96	81.50	51.70	44.00	16.60	53.50	64.40	17.30	69.80	51.90	44.27	39.94
97	79.30	56.00	42.00	14.20	47.60	56.30	11.00	67.20	47.80	45.33	36.02
98	75.50	54.20	42.00	14.20	54.50	65.30	14.90	64.60	49.60	49.11	36.41
99	73.70	50.70	43.20	15.90	51.20	60.00	14.30	60.80	47.00	44.39	42.16
100	75.50	52.30	42.10	14.60	48.30	59.70	12.20	65.30	51.90	44.12	40.92

Appendix XII: Survey on Workers' Requirements of the Sewing Chair Form

Department of Manufacturing Industrial and Textile Engineering,

School of Engineering,

Moi University, Eldoret, Kenya

A. Arranging the Importance of the needs

1. What is the important need of the chair for a sewing workstation? Ranking is in a scale from 1 to 5 (1 is the lowest and 5 is the highest).

No.	Functional requirements	Importance
A.	Adjustable height and back sewing chair	
B.	Adjustable height sewing chair	
C.	Arrow and craft sewing chair	
D.	Camping sewing chair	
E.	Arm sewing chair	
F.	Armless sewing chair	
G.	Sindre sewing chair	
H.	Folding sewing chair	

B. Arranging the Importance of the Factors

2. What is the important factor of the chair for sewing workstation? Ranking is in a scale from 1 to 5 (1 is the lowest and 5 is the highest).

No.	Selection factors	Importance
1.	Ergonomics and safety	
2.	Ease of use	
3.	Ease of manufacture	
4.	Durability	
5.	Aesthetic	
6.	Reliability	
7.	Maintainability	
8.	Social appeal	
9.	Environmental soundness	
10.	Economic value	
11.	Utility and function	
12.	Life cycle cost	
13.	Availability	

Thank you!!!

Appendix XIII: Workers' Survey Data Record

No	A	B	C	D	E	F	G	H	EAS	SOU	EOM	D	Ae	R	M	SA	ES	EV	UAF	LCC	Av
1	5	5	4	5	4	5	5	5	5	5	4	4	3	5	4	4	3	4	5	4	5
2	5	5	4	5	5	4	3	5	5	5	4	4	4	5	4	5	4	4	4	4	5
3	4	2	3	5	2	4	1	3	2	4	3	2	5	1	3	4	2	1	5	4	3
4	5	4	2	4	4	2	3	5	5	5	3	4	2	4	4	3	4	5	4	4	3
5	5	3	2	4	5	3	5	3	2	3	5	4	1	5	1	2	4	1	3	5	2
6	4	1	5	4	3	4	1	2	5	4	5	5	4	3	5	5	3	5	4	4	5
7	1	1	1	5	5	4	5	3	5	5	5	5	4	3	5	5	4	5	4	3	5
8	1	3	5	4	3	3	5	4	2	5	4	5	5	3	5	3	4	4	5	5	4
9	2	1	5	5	4	5	1	5	5	3	2	3	5	4	5	4	3	4	4	1	2
10	5	3	1	2	5	3	1	3	5	4	5	3	3	5	3	4	3	3	4	5	4
11	5	1	3	1	2	5	1	3	5	5	4	5	5	3	5	3	4	3	4	5	4
12	5	3	5	4	1	5	4	1	5	5	4	5	1	2	3	4	5	4	3	4	5
13	3	4	4	5	3	5	4	3	1	4	5	1	4	5	4	5	5	2	1	5	5
14	1	2	2	5	3	5	4	3	4	5	5	1	4	5	4	5	5	2	1	5	5
15	4	4	3	4	1	5	1	1	2	2	1	3	1	4	1	1	1	5	3	1	5
16	4	4	3	5	1	4	1	1	2	2	1	3	1	4	1	1	1	5	3	1	5
17	3	4	4	5	4	3	2	1	5	5	4	5	1	4	3	2	3	2	4	4	5
18	3	4	4	5	4	5	3	4	5	5	4	5	1	2	3	4	5	4	3	4	5
19	4	4	5	4	3	2	2	2	5	5	4	5	3	3	5	3	4	4	4	4	5
20	1	2	3	1	4	5	3	2	5	5	3	4	3	4	4	2	2	4	4	5	5
21	5	5	2	1	3	5	2	1	5	5	1	5	4	4	4	2	3	4	5	1	4
22	5	5	4	1	3	5	1	1	5	5	2	5	3	5	5	4	3	4	4	3	5
23	5	5	3	1	4	5	2	1	5	5	1	5	3	4	2	4	4	3	3	1	5
24	5	5	2	1	3	2	2	1	1	5	4	4	2	3	4	5	3	4	5	1	4
25	5	4	5	5	3	5	5	4	4	5	2	5	2	5	5	5	5	4	4	4	2
26	3	4	5	4	3	5	1	1	5	5	4	5	4	4	5	4	4	4	5	5	5
27	3	4	4	5	5	3	3	4	5	4	4	5	3	5	5	4	5	3	3	4	5
28	5	4	5	1	5	4	5	1	5	5	3	5	4	4	5	5	5	4	5	3	4
29	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
30	2	3	5	1	4	5	1	1	5	5	3	4	4	5	5	5	4	5	3	4	5
31	2	3	5	1	4	5	1	1	5	5	3	5	4	4	5	5	5	4	5	3	4
32	4	5	5	2	3	5	2	3	5	5	4	5	4	3	2	5	4	3	5	4	2
33	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	4	3	3	4	5
34	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
35	5	4	3	4	2	3	1	2	5	4	2	1	2	3	5	4	2	2	3	3	4
36	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
37	5	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
38	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
39	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	5	4	3	4
40	5	5	3	5	4	4	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
41	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
42	4	5	5	2	3	5	2	3	5	4	3	3	2	5	3	3	4	5	3	3	4
43	4	5	5	2	3	5	2	3	5	4	3	3	2	5	3	3	4	4	5	3	3
44	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
45	4	5	5	2	3	5	2	3	5	5	3	5	4	4	4	5	5	4	5	3	4
46	4	5	5	2	3	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
47	5	3	1	1	1	5	5	1	1	5	5	1	1	1	5	5	5	1	1	5	1
48	5	5	1	1	1	5	5	1	1	5	5	1	1	5	5	5	1	1	5	1	1
49	5	5	1	1	5	5	1	1	5	5	5	1	1	5	5	5	1	1	1	5	1
50	2	3	4	2	5	5	4	3	4	4	5	4	3	3	4	4	4	3	2	1	5
51	1	2	3	4	5	5	4	3	4	4	5	4	4	3	4	5	5	4	4	4	5
52	5	1	1	4	5	5	4	4	5	5	5	4	4	5	5	5	4	5	4	4	5
53	5	3	4	4	4	3	2	2	3	2	4	5	3	3	2	4	3	2	2	3	4
54	4	5	4	5	4	5	4	5	5	4	5	4	3	5	4	5	4	5	4	5	4
55	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5
56	5	4	5	4	4	5	5	4	5	5	5	4	4	3	4	5	5	5	4	3	4
57	5	4	5	4	4	5	4	4	4	5	5	4	3	4	5	5	4	4	4	4	4
58	5	4	4	5	4	5	4	5	5	4	3	4	5	4	4	5	4	3	4	5	5
59	5	4	3	5	4	4	5	4	5	4	5	4	5	5	4	3	4	5	4	5	4
60	1	1	1	5	5	4	3	5	5	3	5	5	4	3	5	4	5	5	4	4	5
61	5	4	4	5	4	5	4	5	5	4	5	4	5	4	5	4	5	4	5	4	5
62	4	5	4	5	5	4	4	4	4	5	4	5	5	4	5	4	5	4	4	4	5
63	4	5	4	5	5	4	4	4	4	5	4	5	5	4	4	4	5	5	4	4	4
64	5	4	5	4	5	5	5	4	5	4	3	5	4	5	4	5	4	5	4	5	4
65	4	3	4	5	5	4	4	4	5	4	3	5	5	4	4	3	4	4	5	5	4
66	4	3	4	5	4	4	5	4	5	5	5	5	5	5	4	4	5	5	4	4	4
67	4	3	2	2	2	5	1	3	5	4	3	2	1	1	2	3	4	5	4	4	3
68	4	3	2	2	5	5	1	3	5	4	3	5	3	2	3	4	5	5	4	4	3
69	5	5	1	1	5	5	1	1	5	1	1	1	1	5	5	5	1	1	1	1	5
70	3	3	4	2	1	5	2	1	4	4	5	5	4	5	4	5	5	5	5	4	5
71	3	3	4	2	1	5	2	1	4	4	5	5	4	5	5	4	5	5	5	4	5
72	4	5	5	2	5	5	2	3	5	5	3	5	4	4	5	5	5	4	5	3	4
73	2	4	5	3	2	5	5	3	5	4	5	3	4	4	5	1	5	3	5	4	3
74	5	1	3	2	5	4	3	1	4	5	3	3	4	5	3	4	3	2	4	5	3
75	5	4	3	5	5	4	2	3	2	5	3	4	2	3	5	3	4	3	5	4	3
76	4	4	4	2	3	5	5	3	5	5	5	5	4	5	4	4	3	4	5	4	5
77	5	3	1	2	1	5	2	1	1	2	1	4	4	2	5	5	5	5	2	1	5
78	1	1	1	5	5	5	4	5	5	3	4	5	5	5	4	4	3	5	4	4	5
79	4	1	2	4	5	5	2	1	4	2	1	5	3	2	5	5	2	4	1	5	2
80	2	1	3	4	4	3	4	1	5	4	5	3	4	3	2	1	2	5	4	5	4
81	5	4	3	4	5	5	1	2	5	5	4	5	1	2	4	3	5	4	1	3	5
82	4	4	4	4	4	5	4	4	5	5	4	5	2	3	5	1	5	3	3	4	5
83	1	2	3	2	3	5	2	4	5	1	5	3	2	3	4	2	5	4	3	2	1
84	1	3	2	4	5	5	5	4	4	5	5	1	4	2	5	3	1	5	5	5	5
85	4	2	3	4	1	2	3	4	4	2	4	3	1	2	3	1	1	3	5	5	2
86	1	4	5	5	5	5	1	2	4	5	5	2	1	3	4	1	1	5	4	2	5
87	1	2	4	4	3	5	5	4	5	4	5	3	1	2	3	1	5	4	2	1	5
88	2	1	4	5	3	4	1	2	2	3	5	5	4	4	1	1	2	3	4	3	5
89	2	1	4	5	3	4	1	2	2	3	5	5	4	5	1	1	2	3	5	3	5
90	1	3	4	2	1	5	1	2	3	1	2	3	4	5	3	2	1	4	3	1	5
91	3	4	4	5	4	5	3	4	3	4	5	5	4	5	4	5	5	3	4	5	5
92	5	2	5	3	1	5	2	5	5	5	4	5	3	2	3	2	2	3	3	4	5
93	5	3	1	4	2	5	4	5	5	4	3	2	1	2	4	3	5	3	2	4	5
94	2	5	3	4	1	3	1	1	3	4	1	2	2	3	4	5	5	1	1	2	1
95	2	3	4	3	4	5	1	2	2	1	2	3	4	5	5	4	3	1	2	4	5
96	2	4	5	5	1	2	3	1	2	4	4	5	2	3	3	4	5	5	5	1	2
97	2	3	1	1	2	4	5	5	5	4	5	1	2	3	4	4	3	3	1	2	4
98	1	1	1	3	4	5	3	2	3	5	5	4	3	4	5	4	3	5	4	2	5
99	1	1	3	4	4	5	4	1	5	4	3	5	3	4	3	3	4	5	2	4	5
100	2	3	2	3	4	5	3	2	5	5	4	4	2	3	4	2	5	4	3	5	5

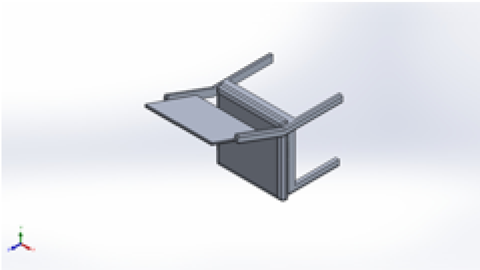
Appendix XIV: FEA Report for Selected Sewing Chair

FEA Static Report

Department of Manufacturing Industrial and Textile Engineering,

School of Engineering,

Moi University, Eldoret, Kenya.



Simulation of the Selected Sewing Chair Model Using SOLIDWORKS Simulation Software.

Date: Sunday, April 28, 2024
Designer: Abdalla Esmaeel
Study name: Static 1
Analysis type: Static

Description

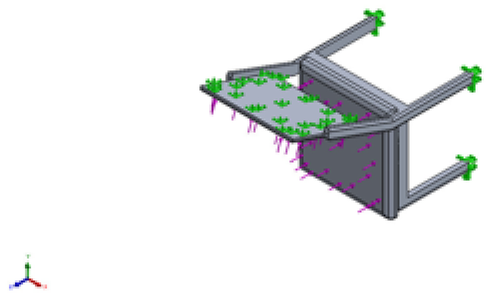
FEA report for the selected sewing chair for used by garment workers at REAL, Eldoret, Kenya.

Table of Contents

Moi University;
Eldoret, Kenya.

Abdalla Esmaeel;
4/28/2024

Model Information



Model name: Full-model of the chair.
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Full-model of the chair..STEP<1>[3]	Solid Body	Mass:30.405 kg Volume:0.0112611 m^3 Density:2,700 kg/m^3 Weight:297.969 N	C:\Users\ESMAEEL\Desktop\FEA Results\Full-model of the chair..SLDPRT Apr 22 19:46:45 2024
Full-model of the chair..STEP<1>[2]	Solid Body	Mass:9.79308 kg Volume:0.00362707 m^3 Density:2,700 kg/m^3 Weight:95.9722 N	C:\Users\ESMAEEL\Desktop\FEA Results\Full-model of the chair..step.SLDPRT Apr 22 19:46:45 2024
Full-model of the chair..STEP<1>[1]	Solid Body	Mass:13.0024 kg Volume:0.00481572 m^3 Density:2,700 kg/m^3 Weight:127.424 N	C:\Users\ESMAEEL\Desktop\FEA Results\Full-model of the chair..step.SLDPRT Apr 22 19:46:45 2024

Moi University;
Eldoret, Kenya.

Abdalla Esmaeel;
4/28/2024

Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (c:\users\esmaeel\appdata\local\temp)

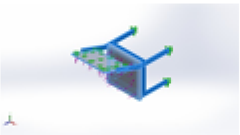
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/mm^2 (MPa)

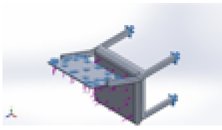
Moi University;
Eldoret, Kenya.

Abdalla Esmaeel;
4/28/2024

Material Properties

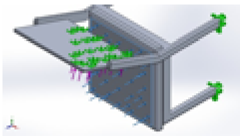
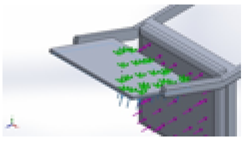
Model Reference	Properties	Components
	Name: 1060 Alloy Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 27.5742 N/mm^2 Tensile strength: 68.9356 N/mm^2 Elastic modulus: 69,000 N/mm^2 Poisson's ratio: 0.33 Mass density: 2.7 g/cm^3 Shear modulus: 27,000 N/mm^2 Thermal expansion coefficient: 2.4e-05 /Kelvin	SolidBody 1(Full-model of the chair. <1> [3]) (Full-model of the chair.), SolidBody 2(Full-model of the chair. <1> [2])(Full-model of the chair.), SolidBody 3(Full-model of the chair. <1> [1]) (Full-model of the chair.)
Curve Data: N/A		

Loads and Fixtures

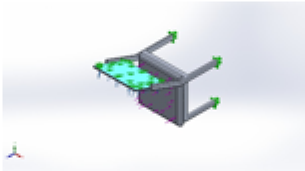
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 5 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-0.00843281	-141.828	848.847	860.614
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 800 N
Force-2		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 150 N

Interaction Information

Interaction	Interaction Image	Interaction Properties
Global Interaction		Type: Bonded Components: 1 component(s) Options: Independent mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	54.0261 mm
Minimum element size	2.70131 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	69620
Total Elements	39657
Maximum Aspect Ratio	34.349
% of elements with Aspect Ratio < 3	98.8
Percentage of elements with Aspect Ratio > 10	0.00504
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:24
Computer name:	

Moi University;
Eldoret, Kenya.

Abdalla Esmaeel;
4/28/2024

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.00843281	-141.828	848.847	860.614

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

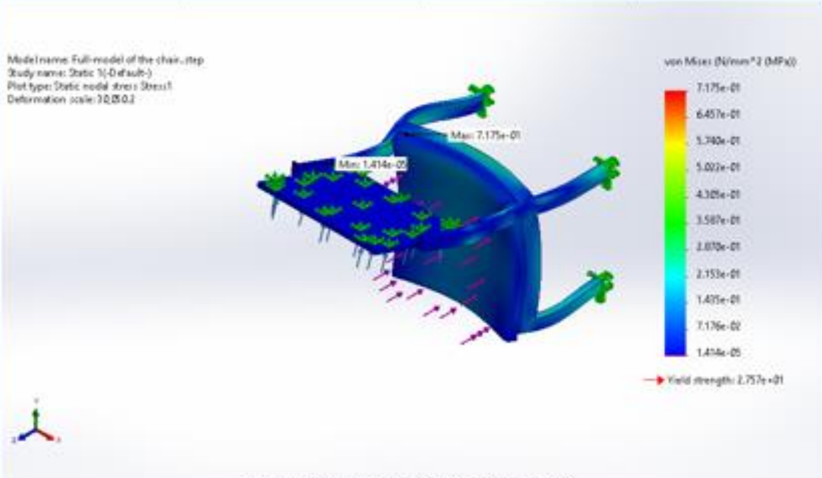
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.0570709	-0.0310618	0.036155	0.074358

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.414e-05N/mm^2 (MPa) Node: 48336	7.175e-01N/mm^2 (MPa) Node: 67581

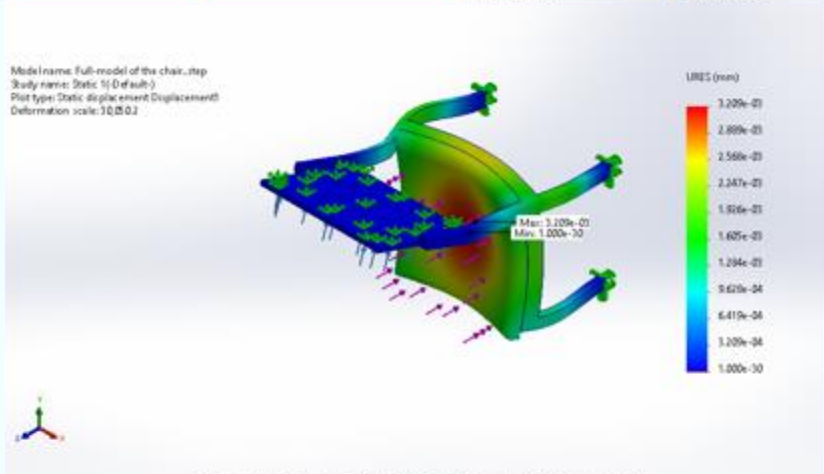


Full-model of the chair.-Static 1-Stress-Stress1

Moi University;
Eldoret, Kenya.

Abdalla Esmaeel;
4/28/2024

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 36303	3.209e-03mm Node: 26013

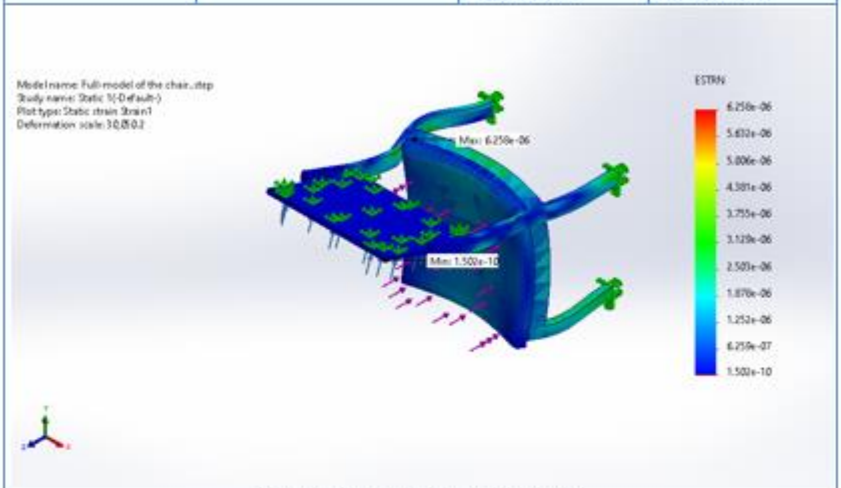


Full-model of the chair.-Static 1-Displacement-Displacement1

Moi University;
Eldoret, Kenya.

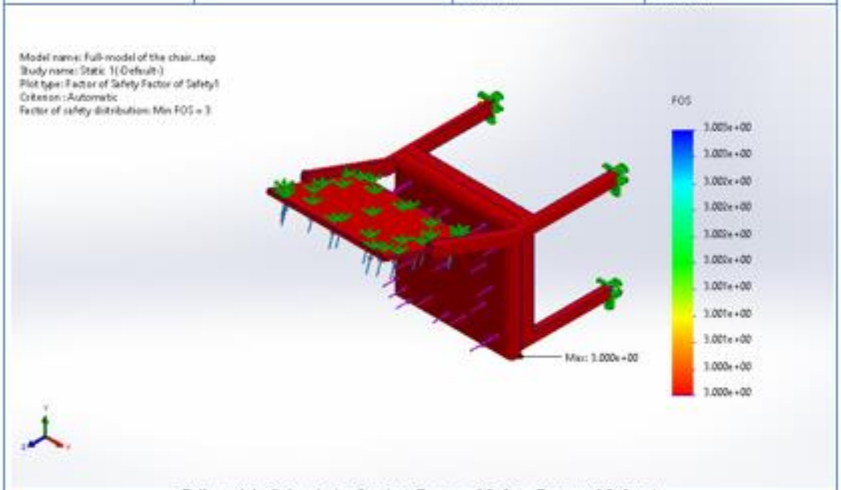
Abdalla Esmaeel;
4/28/2024

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.502e-10 Element: 27300	6.258e-06 Element: 35287



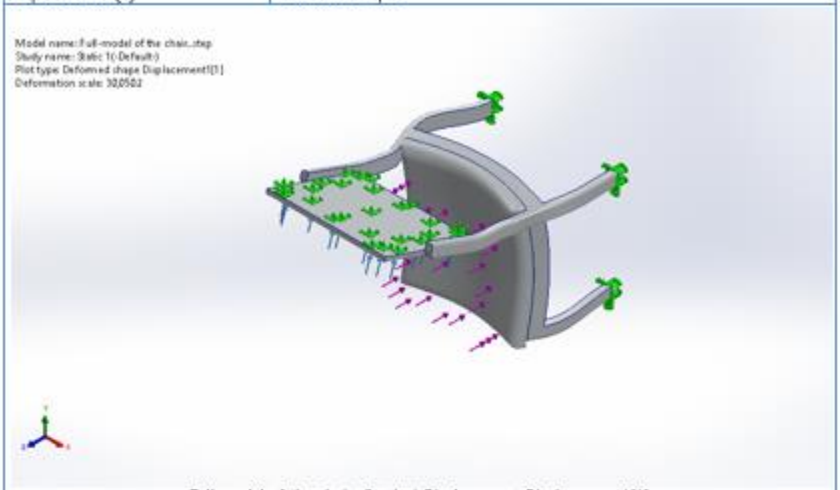
Full-model of the chair.-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	3.000e+00 Node: 1	3.000e+00 Node: 1



Full-model of the chair.-Static 1-Factor of Safety-Factor of Safety1

Name	Type
Displacement1{1}	Deformed shape

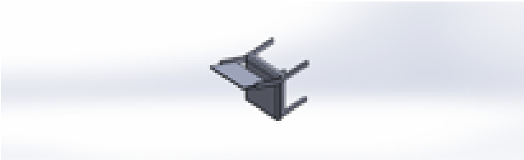


Full-model of the chair.-Static 1-Displacement-Displacement1{1}

Appendix XV: Optimisation Report

Optimisation (design study) report

Department of Manufacturing Industrial and Textile Engineering,
School of Engineering,
Moi University, Eldoret, Kenya.



Optimisation (design study) for the selected sewing chair model using SOLIDWORKS simulation software.

Date: Wednesday, May 29, 2024.

Designer: Abdalla Esmaeel.

Study name: Design Study 1.

Analysis type: Design Study.

Table of Contents

Description

Optimsation (design study) report for the selected sewing chair model for used by garments workers at sewing workstation, REAL, Eldoret, Kenya.

Model Information

Document Name	Configuration	Document Path	Date Modified
Optimization	Default	C:\Users\ESMAEEL\Desktop\A\Optimization	May 26 11:57:38 2024

Study Properties

Study name	Design Study 1
Analysis type	Design Study (Optimization)
Design Study Quality	High quality (slower)
Result folder	SOLIDWORKS document(C:\Users\ESMAEEL\Desktop\A)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/mm^2 (MPa)

Design Study Setup

Design Variables

Name	Type	Value	Units
Height	Range with Step	Min: 411.5 Max: 421.5 Step: 1	mm
Depth	Range with Step	Min: 457 Max: 467 Step: 2	mm
Width	Range with Step	Min: 472.8 Max: 482.8 Step: 3	mm

Constraints

Sensor name	Condition	Bounds	Units	Study name
Stress4	is less than	Max:27570	N/mm^2 (MPa)	Static 1

Goals

Name	Goal	Properties	Weight	Study name
Mass2	Minimize	Mass	10	-

Study Results

332 of 332 scenarios ran successfully.

Component name	Units	Current	Initial	Optimal (1)	Scenario1	Scenario2
Height	mm	416.5	416.5	411.5	411.5	412.5
Depth	mm	462	462	457	457	457
Width	mm	477.8	477.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.933	25.933	26.624	26.624	26.149
Mass2	g	19873.34105	19873.34105	19865.23675	19865.23675	19865.69371

Component name	Units	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	457	457	457	457	457
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.542	26.274	26.662	25.873	26.485
Mass2	g	19866.15068	19866.60764	19867.06461	19867.52075	19867.97853

Component name	Units	Scenario8	Scenario9	Scenario10	Scenario11	Scenario12
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	457	457	457	457	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	27.202	26.081	25.916	27.22	26.527
Mass2	g	19868.43468	19868.89246	19869.34942	19869.80639	19867.56487

Component name	Units	Scenario13	Scenario14	Scenario15	Scenario16	Scenario17
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	459	459	459	459	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.945	26.548	25.878	25.974	26.246
Mass2	g	19868.02184	19868.4788	19868.93576	19869.39273	19869.84887

Component name	Units	Scenario18	Scenario19	Scenario20	Scenario21	Scenario22
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	459	459	459	459	459
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.04	26.956	26.979	25.703	27.249
Mass2	g	19870.30665	19870.7628	19871.22058	19871.67755	19872.13451

Component name	Units	Scenario23	Scenario24	Scenario25	Scenario26	Scenario27
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	461	461	461	461	461
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.883	26.172	26.533	26.123	26.979
Mass2	g	19869.89299	19870.34996	19870.80692	19871.26388	19871.72085

Component name	Units	Scenario28	Scenario29	Scenario30	Scenario31	Scenario32
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	461	461	461	461	461
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.072	26.482	25.783	26.787	26.34
Mass2	g	19872.17699	19872.63478	19873.09092	19873.5487	19874.00567

Component name	Units	Scenario33	Scenario34	Scenario35	Scenario36	Scenario37
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	461	463	463	463	463
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	25.973	26.532	27.356	27.176	25.88
Mass2	g	19874.46263	19872.22111	19872.67808	19873.13504	19873.59201

Component name	Units	Scenario38	Scenario39	Scenario40	Scenario41	Scenario42
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	463	463	463	463	463
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.949	26.572	26.837	25.854	26.471
Mass2	g	19874.04897	19874.50511	19874.9629	19875.41904	19875.87682

Component name	Units	Scenario43	Scenario44	Scenario45	Scenario46	Scenario47
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	463	463	465	465	465
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.932	26.866	26.889	27.214	26.114
Mass2	g	19876.33379	19876.79075	19874.54924	19875.0062	19875.46316

Component name	Units	Scenario48	Scenario49	Scenario50	Scenario51	Scenario52
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	465	465	465	465	465
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	27.1	25.846	25.8	25.976	26.403
Mass2	g	19875.92013	19876.37709	19876.83323	19877.29102	19877.74716

Component name	Units	Scenario53	Scenario54	Scenario55	Scenario56	Scenario57
Height	mm	419.5	420.5	421.5	411.5	412.5
Depth	mm	465	465	465	467	467
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.608	26.533	25.795	26.842	26.907
Mass2	g	19878.20495	19878.66191	19879.11887	19876.87736	19877.33432
Component name	Units	Scenario58	Scenario59	Scenario60	Scenario61	Scenario62
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	467	467	467	467	467
Width	mm	472.8	472.8	472.8	472.8	472.8
Stress4	N/mm^2 (MPa)	26.213	26.353	25.75	26.115	27.043
Mass2	g	19877.79128	19878.24825	19878.70521	19879.16136	19879.61914

Component name	Units	Scenario63	Scenario64	Scenario65	Scenario66	Scenario67
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	467	467	467	467	457
Width	mm	472.8	472.8	472.8	472.8	475.8
Stress4	N/mm^2 (MPa)	27.021	26.318	26.124	26.029	26.584
Mass2	g	19880.07528	19880.53307	19880.99003	19881.44699	19865.23675

Component name	Units	Scenario68	Scenario69	Scenario70	Scenario71	Scenario72
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	457	457	457	457	457
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.151	26.542	26.274	26.662	25.913
Mass2	g	19865.69371	19866.15068	19866.60764	19867.06461	19867.52075

Component name	Units	Scenario73	Scenario74	Scenario75	Scenario76	Scenario77
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	457	457	457	457	457
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.485	27.201	26.081	25.916	27.22
Mass2	g	19867.97853	19868.43468	19868.89246	19869.34942	19869.80639

Component name	Units	Scenario78	Scenario79	Scenario80	Scenario81	Scenario82
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	459	459	459	459	459
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.527	25.945	26.549	25.878	25.974
Mass2	g	19867.56487	19868.02184	19868.4788	19868.93576	19869.39273

Component name	Units	Scenario83	Scenario84	Scenario85	Scenario86	Scenario87
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	459	459	459	459	459
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.246	25.952	26.956	26.979	25.702
Mass2	g	19869.84887	19870.30665	19870.7628	19871.22058	19871.67755

Component name	Units	Scenario88	Scenario89	Scenario90	Scenario91	Scenario92
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	459	461	461	461	461
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	27.249	26.882	26.022	26.538	26.125
Mass2	g	19872.13451	19869.89299	19870.34996	19870.80692	19871.26388
Component name	Units	Scenario93	Scenario94	Scenario95	Scenario96	Scenario97
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	461	461	461	461	461
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.949	26.072	26.482	25.818	26.786
Mass2	g	19871.72085	19872.17699	19872.63478	19873.09092	19873.5487

Component name	Units	Scenario98	Scenario 99	Scenario100	Scenario101	Scenario102
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	461	461	463	463	463
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.339	25.973	26.532	27.356	27.349
Mass2	g	19874.00567	19874.46263	19872.22111	19872.67808	19873.13504

Component name	Units	Scenario103	Scenario104	Scenario105	Scenario106	Scenario107
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	463	463	463	463	463
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	25.882	26.817	26.566	26.837	26.124
Mass2	g	19873.59201	19874.04897	19874.50511	19874.9629	19875.41904

Component name	Units	Scenario108	Scenario109	Scenario110	Scenario111	Scenario112
Height	mm	419.5	420.5	421.5	411.5	412.5
Depth	mm	463	463	463	465	465
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.552	26.933	26.869	26.889	27.214
Mass2	g	19875.87682	19876.33379	19876.79075	19874.54924	19875.0062

Component name	Units	Scenario113	Scenario114	Scenario115	Scenario116	Scenario117
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	465	465	465	465	465
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.114	27.1	25.846	25.8	25.975
Mass2	g	19875.46316	19875.92013	19876.37709	19876.83323	19877.29102

Component name	Units	Scenario118	Scenario119	Scenario120	Scenario121	Scenario122
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	465	465	465	465	467
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.403	26.608	26.533	25.795	26.841
Mass2	g	19877.74716	19878.20495	19878.66191	19879.11887	19876.87736

Component name	Units	Scenario123	Scenario124	Scenario125	Scenario126	Scenario127
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	467	467	467	467	467
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	26.907	26.327	26.529	25.748	26.115
Mass2	g	19877.33432	19877.79128	19878.24825	19878.70521	19879.16136

Component name	Units	Scenario128	Scenario129	Scenario130	Scenario131	Scenario132
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	467	467	467	467	467
Width	mm	475.8	475.8	475.8	475.8	475.8
Stress4	N/mm^2 (MPa)	27.043	27.017	26.318	26.124	26.029
Mass2	g	19879.61914	19880.07528	19880.53307	19880.99003	19881.44699

Component name	Units	Scenario133	Scenario134	Scenario135	Scenario136	Scenario137
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	457	457	457	457	457
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.624	26.149	26.542	26.274	26.717
Mass2	g	19865.23675	19865.69371	19866.15068	19866.60764	19867.06461

Component name	Units	Scenario138	Scenario139	Scenario140	Scenario141	Scenario142
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	457	457	457	457	457
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	25.873	26.485	27.202	26.081	25.916
Mass2	g	19867.52075	19867.97853	19868.43468	19868.89246	19869.34942

Component name	Units	Scenario143	Scenario144	Scenario145	Scenario146	Scenario147
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	457	459	459	459	459
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	27.22	26.527	25.945	26.547	25.878
Mass2	g	19869.80639	19867.56487	19868.02184	19868.4788	19868.93576

Component name	Units	Scenario148	Scenario149	Scenario150	Scenario151	Scenario152
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	459	459	459	459	459
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	25.974	26.246	25.952	26.956	26.979
Mass2	g	19869.39273	19869.84887	19870.30665	19870.7628	19871.22058

Component name	Units	Scenario153	Scenario154	Scenario155	Scenario156	Scenario157
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	459	459	461	461	461
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	25.703	27.249	26.883	26.136	26.533
Mass2	g	19871.67755	19872.13451	19869.89299	19870.34996	19870.80692

Component name	Units	Scenario158	Scenario159	Scenario160	Scenario161	Scenario162
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	461	461	461	461	461
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.123	26.979	26.072	26.482	25.783
Mass2	g	19871.26388	19871.72085	19872.17699	19872.63478	19873.09092

Component name	Units	Scenario163	Scenario164	Scenario165	Scenario166	Scenario167
Height	mm	419.5	420.5	421.5	411.5	412.5
Depth	mm	461	461	461	463	463
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.787	26.339	25.973	26.532	27.356
Mass2	g	19873.5487	19874.00567	19874.46263	19872.22111	19872.67808

Component name	Units	Scenario168	Scenario169	Scenario170	Scenario171	Scenario172
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	463	463	463	463	463
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	27.174	25.88	26.931	26.572	26.837
Mass2	g	19873.13504	19873.59201	19874.04897	19874.50511	19874.9629

Component name	Units	Scenario173	Scenario174	Scenario175	Scenario176	Scenario177
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	463	463	463	463	465
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	25.854	26.553	26.932	26.866	26.889
Mass2	g	19875.41904	19875.87682	19876.33379	19876.79075	19874.54924

Component name	Units	Scenario178	Scenario179	Scenario180	Scenario181	Scenario182
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	465	465	465	465	465
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	27.214	26.383	27.1	25.846	25.8
Mass2	g	19875.0062	19875.46316	19875.92013	19876.37709	19876.83323

Component name	Units	Scenario183	Scenario184	Scenario185	Scenario186	Scenario187
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	465	465	465	465	465
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.003	26.403	26.608	26.533	25.795
Mass2	g	19877.29102	19877.74716	19878.20495	19878.66191	19879.11887

Component name	Units	Scenario188	Scenario189	Scenario190	Scenario191	Scenario192
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	467	467	467	467	467
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.842	26.907	26.213	26.527	25.75
Mass2	g	19876.87736	19877.33432	19877.79128	19878.24825	19878.70521

Component name	Units	Scenario193	Scenario194	Scenario195	Scenario196	Scenario197
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	467	467	467	467	467
Width	mm	478.8	478.8	478.8	478.8	478.8
Stress4	N/mm^2 (MPa)	26.115	27.043	27.021	26.318	26.124
Mass2	g	19879.16136	19879.61914	19880.07528	19880.53307	19880.99003

Component name	Units	Scenario198	Scenario199	Scenario200	Scenario201	Scenario202
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	467	457	457	457	457
Width	mm	478.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.029	26.624	26.149	26.542	26.274
Mass2	g	19881.44699	19865.23675	19865.69371	19866.15068	19866.60764

Component name	Units	Scenario203	Scenario204	Scenario205	Scenario206	Scenario207
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	457	457	457	457	457
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.662	25.873	26.485	27.203	26.081
Mass2	g	19867.06461	19867.52075	19867.97853	19868.43468	19868.89246

Component name	Units	Scenario208	Scenario209	Scenario210	Scenario211	Scenario212
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	457	457	459	459	459
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.916	27.22	26.527	25.945	26.547
Mass2	g	19869.34942	19869.80639	19867.56487	19868.02184	19868.4788

Component name	Units	Scenario213	Scenario214	Scenario215	Scenario216	Scenario217
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	459	459	459	459	459
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.878	25.974	26.246	25.952	26.956
Mass2	g	19868.93576	19869.39273	19869.84887	19870.30665	19870.7628

Component name	Units	Scenario218	Scenario219	Scenario220	Scenario221	Scenario222
Height	mm	419.5	420.5	421.5	411.5	412.5
Depth	mm	459	459	459	461	461
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.979	25.703	27.248	26.883	26.136
Mass2	g	19871.22058	19871.67755	19872.13451	19869.89299	19870.34996

Component name	Units	Scenario223	Scenario224	Scenario225	Scenario226	Scenario227
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	461	461	461	461	461
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.533	26.123	26.979	26.072	26.482
Mass2	g	19870.80692	19871.26388	19871.72085	19872.17699	19872.63478

Component name	Units	Scenario228	Scenario229	Scenario230	Scenario231	Scenario232
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	461	461	461	461	463
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.783	26.787	26.339	25.973	26.532
Mass2	g	19873.09092	19873.5487	19874.00567	19874.46263	19872.22111

Component name	Units	Scenario233	Scenario234	Scenario235	Scenario236	Scenario237
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	463	463	463	463	463
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	27.356	27.174	25.88	26.931	26.572
Mass2	g	19872.67808	19873.13504	19873.59201	19874.04897	19874.50511

Component name	Units	Scenario238	Scenario239	Scenario240	Scenario241	Scenario242
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	463	463	463	463	463
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.837	25.854	26.576	26.932	26.866
Mass2	g	19874.9629	19875.41904	19875.87682	19876.33379	19876.79075

Component name	Units	Scenario243	Scenario244	Scenario245	Scenario246	Scenario247
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	465	465	465	465	465
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	26.889	27.214	26.383	27.1	25.846
Mass2	g	19874.54924	19875.0062	19875.46316	19875.92013	19876.37709

Component name	Units	Scenario248	Scenario249	Scenario250	Scenario251	Scenario252
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	465	465	465	465	465
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.8	26.003	26.403	26.608	26.533
Mass2	g	19876.83323	19877.29102	19877.74716	19878.20495	19878.66191

Component name	Units	Scenario253	Scenario254	Scenario255	Scenario256	Scenario257
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	465	467	467	467	467
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.795	26.842	26.907	26.213	26.527
Mass2	g	19879.11887	19876.87736	19877.33432	19877.79128	19878.24825

Component name	Units	Scenario258	Scenario259	Scenario260	Scenario261	Scenario262
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	467	467	467	467	467
Width	mm	481.8	481.8	481.8	481.8	481.8
Stress4	N/mm^2 (MPa)	25.75	26.116	27.132	27.021	26.318
Mass2	g	19878.70521	19879.16136	19879.61914	19880.07528	19880.53307

Component name	Units	Scenario263	Scenario264	Scenario265	Scenario266	Scenario267
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	467	467	457	457	457
Width	mm	481.8	481.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.124	26.029	26.684	26.151	26.542
Mass2	g	19880.99003	19881.44699	19865.23675	19865.69371	19866.15068

Component name	Units	Scenario268	Scenario269	Scenario270	Scenario271	Scenario272
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	457	457	457	457	457
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.274	26.662	25.913	26.485	27.218
Mass2	g	19866.60764	19867.06461	19867.52075	19867.97853	19868.43468

Component name	Units	Scenario273	Scenario274	Scenario275	Scenario276	Scenario277
Height	mm	419.5	420.5	421.5	411.5	412.5
Depth	mm	457	457	457	459	459
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	25.825	25.916	27.22	26.648	25.945
Mass2	g	19868.89246	19869.34942	19869.80639	19867.56487	19868.02184

Component name	Units	Scenario278	Scenario279	Scenario280	Scenario281	Scenario282
Height	mm	413.5	414.5	415.5	416.5	417.5
Depth	mm	459	459	459	459	459
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.547	25.878	25.974	26.246	25.952
Mass2	g	19868.4788	19868.93576	19869.39273	19869.84887	19870.30665

Component name	Units	Scenario283	Scenario284	Scenario285	Scenario286	Scenario287
Height	mm	418.5	419.5	420.5	421.5	411.5
Depth	mm	459	459	459	459	461
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.956	26.979	25.703	27.249	26.838
Mass2	g	19870.7628	19871.22058	19871.67755	19872.13451	19869.89299

Component name	Units	Scenario288	Scenario289	Scenario290	Scenario291	Scenario292
Height	mm	412.5	413.5	414.5	415.5	416.5
Depth	mm	461	461	461	461	461
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.022	26.538	26.123	26.949	26.072
Mass2	g	19870.34996	19870.80692	19871.26388	19871.72085	19872.17699

Component name	Units	Scenario293	Scenario294	Scenario295	Scenario296	Scenario297
Height	mm	417.5	418.5	419.5	420.5	421.5
Depth	mm	461	461	461	461	461
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.482	25.817	26.787	26.339	25.973
Mass2	g	19872.63478	19873.09092	19873.5487	19874.00567	19874.46263

Component name	Units	Scenario298	Scenario299	Scenario300	Scenario301	Scenario302
Height	mm	411.5	412.5	413.5	414.5	415.5
Depth	mm	463	463	463	463	463
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	25.992	27.356	27.349	25.882	26.817
Mass2	g	19872.22111	19872.67808	19873.13504	19873.59201	19874.04897

Component name	Units	Scenario303	Scenario304	Scenario305	Scenario306	Scenario307
Height	mm	416.5	417.5	418.5	419.5	420.5
Depth	mm	463	463	463	463	463
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.566	26.837	26.12	26.552	26.932
Mass2	g	19874.50511	19874.9629	19875.41904	19875.87682	19876.33379

Component name	Units	Scenario308	Scenario309	Scenario310	Scenario311	Scenario312
Height	mm	421.5	411.5	412.5	413.5	414.5
Depth	mm	463	465	465	465	465
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.869	26.587	27.214	26.355	27.1
Mass2	g	19876.79075	19874.54924	19875.0062	19875.46316	19875.92013

Component name	Units	Scenario313	Scenario314	Scenario315	Scenario316	Scenario317
Height	mm	415.5	416.5	417.5	418.5	419.5
Depth	mm	465	465	465	465	465
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	25.846	25.798	25.976	26.403	26.608
Mass2	g	19876.37709	19876.83323	19877.29102	19877.74716	19878.20495

Component name	Units	Scenario318	Scenario319	Scenario320	Scenario321	Scenario322
Height	mm	420.5	421.5	411.5	412.5	413.5
Depth	mm	465	465	467	467	467
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.533	25.795	26.764	26.905	26.327
Mass2	g	19878.66191	19879.11887	19876.87736	19877.33432	19877.79128

Component name	Units	Scenario323	Scenario324	Scenario325	Scenario326	Scenario327
Height	mm	414.5	415.5	416.5	417.5	418.5
Depth	mm	467	467	467	467	467
Width	mm	482.8	482.8	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.48	25.748	26.116	27.043	27.017
Mass2	g	19878.24825	19878.70521	19879.16136	19879.61914	19880.07528

Component name	Units	Scenario328	Scenario329	Scenario330
Height	mm	419.5	420.5	421.5
Depth	mm	467	467	467
Width	mm	482.8	482.8	482.8
Stress4	N/mm^2 (MPa)	26.318	26.124	26.029
Mass2	g	19880.53307	19880.99003	19881.44699

Appendix XVI: Publications

Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.14, No.1, 2024

www.iiste.org

Work-Related Risks and Hazards for Garment Making Workers at Sewing Workstations: A Review.

Abdalla Esmaeel[1, 2, 3*], Diana Starovoytova[1], Patrick Nziu[1] and Jerry Ochola[1].

1. Department of Manufacturing, Textile and Industrial Engineering, School of Engineering, Moi University, Eldoret, Kenya.
2. Africa Centre of Excellence in Phytochemical, Textile and Renewable Energy (ACEII PTRE), Moi University, Eldoret, Kenya.
3. Department of Industrial Engineering, Faculty of Industries Engineering and Technology, University of Gezira, Sudan.

*Corresponding author's e-mail: abdalla33065@gmail.com

Abstract

Awkwardly designed sewing workstations in garment manufacturing cause work-related risks and hazards that raise global health concerns for industrial sewing workers and the environment. In this review, therefore, most of the studies showed that work-related musculoskeletal disorders (WMSDs) are a major problem throughout the world. However, strategies to control this risk typically focus on redesigning sewing workstations to reduce the ergonomic hazards that workers experience during their work performance. Though the best way to have a safer workstation without any injuries during the work is to assess the risks and hazards of WMSD. The aim of this review study, therefore, is to assess work-related risks and hazards for garment-making workers at sewing workstations. Furthermore, there are three primary risk factors that are essentially physical in nature, such as forceful exertions, high task repetitions, and awkward postures. Besides, the most common hazards at the workstation are safety hazards, biological hazards, physical hazards, ergonomic hazards, chemical hazards, work and person hazards, fire hazards, and environmental hazards. In addition, there are many ways to reduce ergonomic risks and hazards that can help fit the sewing workstation to the worker. Additionally, solutions can be grouped into ten main categories, such as eliminating the risks and hazards, substituting the risks and hazards, engineering controls, visual and audible warnings, administrative controls, improving work policies and procedures, work practice controls, counteractive stretch breaks, a job rotation program, and providing personal protective equipment. This review therefore suggested a study on ergonomic hazards for making workers realize the importance of ergonomics for assessing potential ergonomic risks and hazards factors that existed around their sewing workstation. For ergonomic assessment methods, RULA and REBA are used to review studies from different researchers. In contrast, both survey-based methods show their significance and are suitable and accurate to assess the risk and hazards of ergonomics in the workers' working environment. This review study, therefore, suggested both methods as the most popular and widely used observational ergonomic assessment tools in various industries and services. It is hoped that the review and discussion can inspire more researchers to take part in this present review study.

Keywords: Garments industry, RULA, Ergonomic hazards, WMSD, REBA.

DOI: 10.7176/ISDE/14-1-06

Publication date: June 30th 2024

Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.14, No.1, 2024

www.iiste.org

Design and Simulation Ergonomically Sewing Chair for Garment Manufacturing Workers

Abdalla Esmaeel[1, 2, 3*], Diana Starovoytova[1] and Jerry Ochola[1].

1. Department of Manufacturing, Textile and Industrial Engineering, School of Engineering, Moi University, Eldoret, Kenya.
2. Africa Centre of Excellence in Phytochemical, Textile and Renewable Energy (ACEII PTRE), Moi University, Eldoret, Kenya.
3. Department of Industrial Engineering, Faculty of Industries Engineering and Technology, University of Gezira, Sudan.

*Corresponding author's e-mail: abdalla33065@gmail.com

Abstract

In garment-making industries, workers have to work for more than eight hours continually either by sitting or by standing in one position. Therefore, stress is developed in their bodies, which might lead to musculoskeletal disorders (MSDs). The purposed of this paper is to explain the design and simulation of an ergonomic sewing chair workstation for workers at garments manufacturing, Rivatex East Africa Limited (REAL), Eldoret, Kenya. The SOLIDWORKS 2023 software (design and simulation tool), was used to develop an ergonomic design of the sewing chair workstation based on the worker's anthropometric data. The model of an ergonomically sewing chair was simulated using SOLIDWORKS software based on Finite Element Analysis (FEA) test with a deformation scale of 30,050.2 to check its ability to withstand the weight of the human body. The loads applied were 800 N on the base seat and 150 N on the backrest of the seat. The aluminium alloy 1060 was selected for FEA test with a yield strength of 2.757e + 01 N/mm^2 and tensile strength of 6.893e + 01 N/mm^2. The FEA criteria included stress, displacement, strain and Factor of Safety (FOS). The FEA results showed that the aluminium model passed the test satisfactorily, due to the many criteria: the maximum stress is 7.175e-01 N/mm^2 and does not exceed the yield strength of the material, which was acceptable; the maximum displacement was 3.209e–03 mm, thus, the maximum deformation becomes 0.03209 mm, which was below the assigned safety level; the maximum strain established from the results was 6.258e-06 which was can be considered within the range for the material, which meant that the model would not break or fail due the applied loads. It was also established from the results that there was a minimum FOS distribution value of 3 from the model analysis. This implied that the model needs 3 times of loads applied to deform the selected material, which could be considered within the range safety limits. This research study can be extended by fabricating and manufacturing the proposed sewing chair model and validating the sewing chair design by experimental study.

Keywords: Sewing chair, Ergonomic design, Simulation, FEA, SOLIDWORKS Simulation.

DOI: 10.7176/ISDE/14-1-07
Publication date: September 30th 2024

Risk Assessment and Management Decisions

www.ramd.reapress.com

Risk Assess. Manage. Decis.Vol. 2, No. 2 (2025) 87–103.

Paper Type: Original Article

Work-Related Musculoskeletal Disorders for Garments-Making Employees at Sewing Workplace

Abdalla Esmaeel[1, 2, 3,*] , Diana Starovoytova[3], Jerry Ochola[3]

[1] Department of Industrial Engineering, Faculty of Industries Engineering and Technology, University of Gezira P. O. Box 20, Wad Madani, Sudan; abdalla33065@gmail.com.

[2] Africa Center of Excellence in Phytochemicals, Textile, and Renewable Energy (ACEII-PTRE), Moi University P. O. Box 3900, Eldoret, Kenya; drdsmeld@yahoo.com.

[3] Department of Manufacturing, Industrial and Textile Engineering, School of Engineering, Moi University P. O. Box 3900, Eldoret, Kenya; jerry.ochola@mu.ac.ke.

Citation:

Received: 14 Jun 2024 *Revised: 04 August 2024* *Accepted: 28 September 2024*	Esmaeel, A., Starovoytova, D., & Ochola, J. (2025). Work-related musculoskeletal disorders for garments-making employees at sewing workplace. *Risk assessment and management decisions*, 2(2), 87-103.

Abstract

Work-related Musculoskeletal Disorders (MSDs) have become one of the main problems in the working environment, and it increases employees' risk of illness. This health problem, however, may contribute to the long-run effects on production performance. The aim of this paper, therefore, was to assess the work-related MSDs for garments-making employees at the sewing workplace, Rivatex East Africa Limited (REAL), Eldoret, Kenya. In order to determine the working postures and identification of the hazard and risk factors of the MSD system depending on the working posture. Rapid Entire Body Analysis (REBA) was used to assess the ergonomic work-related MSDs. The analysis results of employee posture for the existing sewing workplace had a final REBA score of 5, which meant that there was a medium ergonomic risk of MSDs and changes needed. In conclusion, the findings from this paper showed that the existing sewing workplace at the REAL factory needs to be redesigned in order to reduce awkward postures and anthropometric mismatches to lower MSD problems and improve productivity among employees.

Keywords: MSDs, Working environment, REBA, Ergonomic risk, REAL factory.

Appendix XVII: Plagiarism Report (Turnitin)

similarity

ORIGINALITY REPORT

14%
SIMILARITY INDEX

PRIMARY SOURCES

1	ebin.pub Internet	4643 words	6%
2	ir.mu.ac.ke:8080 Internet	2230 words	3%
3	www2.uwstout.edu Internet	1949 words	2%
4	hdl.handle.net Internet	907 words	1%
5	Jegatheswaran Ratnasingam. "Furniture Manufacturing", Springer Science and Business Media LLC, 2022 Crossref	834 words	1%
6	www.coursehero.com Internet	556 words	1%
7	link.springer.com Internet	521 words	1%

Appendix XVIII: Plagiarism Awareness Certificate

SR779

ISO 9001:2019 Certified Institution

THESIS WRITING COURSE

PLAGIARISM AWARENESS CERTIFICATE

This certificate is awarded to

ABDALLA E. A. ESMAEEL

PHD/IE/5675/22.

In recognition for passing the University's plagiarism

Awareness test for Thesis **entitled**: **ERGONOMIC REDESIGN OF SEWING WORKSTATION FOR GARMENTS MANUFACTURING;CASE STUDY AT RIVATEX EAST AFRICA LIMITED, ELDORET, KENYA with** similarity index of 14% and striving to maintain academic integrity.

Word count:78095

Awarded by

Prof. Anne Syomwene Kisilu

CERM-ESA Project Leader Date: 12/02//2025