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Design and Simulation Ergonomically Sewing Chair for Garment Manufacturing Workers

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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.

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1. Introduction

1.1 Sewing workstation

In garment industries workers have to work for more than eight hours repeatedly either by sitting or by standing in one position causing stress to develop in their system leading to musculoskeletal disorders (MSDs) (Ali, 2014). In the previous study by Chan et al., (2002) to date, there have been relatively few intervention projects relating to MSDs among sewing machine operators. According to Li et al., (1995), sewing workers suffer from musculoskeletal problems, which have been attributed to poor working postures as well as to repetitive hand and arm movements.

As stated in the previous study by Halpern & Dawson, (1997) specifically in the garment industry, the incidence of MSD reported by sewing machine operators appears to be increasing. Recent research by Ahmed, (2018) suggested for low-cost ergonomic solution i.e. use of a thread cone to adjust the chair height and wooden pieces to uplift the sewing table to adjust to the worker's body dimensions. A previous study by Gade et al., (2015) shows that sewing machine operators face a substantially higher risk of muscle pain and injury than workers in other jobs.

In the Apparel manufacturing process, sewing is one of the most important operations. Most of such industrial sewing is done by industrial sewing machines (Syduzzaman & Golder, 2015). An earlier study by Khan et al., (2022) stated that scientifically designed sewing workstations reduce muscular-skeletal diseases. In addition, the workstations for garments and textiles included cutting section, dyeing, visual inspection, pressing and sewing (Leilanie, 2004). According to Nejad et al., (2020), the sewing chair workstation is one of the occupations where the prevalence of MSDs is high.

As stated by Pagnan & Câmara, (2012) for the individual workplace (sewing machines workstation) would be ideal if there were more lights focused on the machines. According to Ramdass & du, (2007), some tasks require operator training in contortionist sewing techniques which is done in the workplace. Besides, the human body cannot adapt to every situation. People have differences and they have limitations, and this issue is not evaluated thoroughly before contracting people on the job.

According to Aribowo et al., (2020), garment assembly operation practice is one of the courses in the garment study program. It is a process of learning to sew components into apparel using a single-needle sewing machine workstation. According to Habib, (2015), many sewing machine operators are working with high-risk factors for musculoskeletal health in the garments industries in Bangladesh. Also, a study by Shah et al., (2016) stated that the garment manufacturing industry is highly labour-intensive, especially in developing countries like Pakistan.

Previous research by H et al., (2014) presents an ergonomic assessment of the workstations in cutting and sewing sections of a garment manufacturing industry in Bangalore and aims at the identification of the "bad ergonomics" leading to worker's health problems and suggests interventions for developing ergonomic workstations. A study by Harrison et al., (2008) stated that a typical sewing workstation has a flat work surface (51 * 122 cm) that can be adjusted by a mechanic to heights of 76 to 86 cm; but the height is usually fixed at 76 cm.

Additionally, in the case of sewing workstation design the floor space is around four (4) square meters in cases where larger products are manufactured such as curtains, tents or rugs (Patil et al., 2017). At a traditional sewing machine workstation, many health problems and MSDs are reported (Sheta et al., 2018). According to Eladly et al., (2020), the experiment was designed to formulate guidelines for the ergonomic redesign of the sewing workstation to fit each anthropometric trail.

According to recent study by Esmaeel et al., (2024) stated that an awkwardly designed sewing chairs in garment manufacturing cause work-related risks and hazards that raise global health concerns for industrial sewing workers and the environment. In this study, therefore, most of the studies showed that work related musculoskeletal disorders (WRMSDs) are a major problem throughout the world. However, strategies to control this risk typically focus on designing ergonomically sewing chairs for garments manufacturing workers to reduce the ergonomic hazards that workers experience during their work performance.

1.2 Anthropometric data

According to Mohd & Esa, (2021), an anthropometric measurement is the collection of physical characteristics of the human body that are relevant to ergonomic design, physical body anthropology, clothing size, consumer product design, tool design, and equipment, among other fields. These characteristics include size, body shape, strength in static and dynamic conditions, and ability to perform work. In the static state, measurements of length, width, height, and circumference are taken whereas in the dynamic condition, measurements of speed and ranges of motion are taken. The static condition also includes any adopted postures such as sitting or standing. Whenever an anthropometric measurement is considered for design/redesign, it helps to improve comfortability level, reduce low back pain, and musculoskeletal disorders and increase the performance of the user as well.

Research by Taifa & Desai, (2017) defines anthropometry as ''the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body". In simple meaning, Anthropometry can be defined as the study which deals with body dimensions i.e. body size, shape, strength and working capacity for design purposes and body composition. By the early 1990s, several manufacturers commenced the mass production of modern furniture, especially chairs in different sizes and dimensions, based on reliance on the anthropometric data available to the designers (Oyewole et al., 2010).

According to Silviana et al., (2022), the design process should consider many factors, such as the anthropometric data. In addition to that anthropometry is a process of measuring the human body's mass properties and its physical dimension. According to Esmaeel et al., (2020), anthropometric data is used in ergonomics to fit the workplace to the man, rather than fit the man to the workplace. Additionally, for ergonomists, one of the main concerns is that controls and meters are readable and reachable. Therefore, this first design was based on anthropometric data provided in the standard IEC-964 (Burns & Vicente, 2000).

A previous study by Obinna et al., (2021) stated that the purpose is not only to critique the ergonomic suitability of the sewing furniture but to also present anthropometric data which could be used in the future for making better-suited sewing furniture. According to Ali, (2014), anthropometric data are used in ergonomics to specify the physical dimensions of workspaces, equipment, furniture and clothing to "inshape the task to the man" and to ensure that the physical mistakes between the dimensions of equipment and products and matching user dimension are avoided.

Studies of the anthropometric features of the proximal femur and the anterior femoral curve in the femora from a Kenyan population have found these features to be different from those of other populations (Mukulu

Ndeleva, 2017). According to Ulijaszek & Komlos, (2010), anthropometry is the longest-used measure of human variation, and since it measures surface morphology, is intuitively understood at the elementary level. A previous study by Adeyemi et al., (2019) stated that African countries, including Nigeria, have not shown enough commitment to this need as most African countries are yet to possess an anthropometric database that is needed for such standardization.

Current practice also fails to account for anthropometric diversity in the workforce and does not use the potential of multi-objective simulation-based optimization techniques (Pascual et al., 2021). According to Yadav et al., (2017), the placement of controls is a complex task for the designer who must take into account the anthropometric characteristics of the target population. Although there are a huge number of studies in industrialized countries which determine the anthropometric measurements of male and female workers employed in many sectors, the number of studies treating the anthropometric measurements of workers in the textile sector is limited (Kalınkara et al., 2011).

1.3 Ergonomic design

According to Esmaeel et al., (2020), the basic philosophy of ergonomics is to make any design of a sewing workstation which leads to comfort, physical health, safety, well-being, and convenience and brings motive towards studies. According to Avadanei et al., (2022), ergonomic designs recognize the harmonious relationship between the human body, clothing, and the environment as well as the importance of "beauty in the form" and "efficiency" in clothing design. A previous study by Esmaeel et al., (2022) stated that whenever designers wish to have adjustable classroom furniture which is ergonomically designed based on anthropometric data.

A study by Eladly et al., (2020) stated that the experiment was designed to formulate guidelines for the ergonomic redesign of the sewing workstation to fit each anthropometric trail. As a result, operators' postures are constrained by four workstation setting factors, which were assigned for study. Previous research by Aribowo et al., (2020) found that the existing sewing machine workstation has fixed height at the table and the chair which is not based on the ergonomic aspects of working posture. According to Esmaeel et al., (2020), ergonomics is a science focused on the study of human fit, decreased fatigue, risk, hazed and discomfort through product design.

Previous research by Harari et al., (2017) specified that when designing a workstation with manual material handling tasks, it is important to study both ergonomics and production. According to Gopura & Amarasena, (2008), ergonomically designed chairs are important for long-time seated workers to increase their productivity and also to reduce low back injuries due to the use of poorly designed chairs in ergonomic aspects. In addition, ergonomically designed chairs increase the seating comfortability of the chair users. Most of the chairs designed for long-time seated workers are not considered the full ergonomic aspects.

According to Yadav et al., (2017) the compatibility of human capabilities and limitations, in conjunction with operations and work environment, with the ways of designing machines is dealt with within ergonomics principles. An earlier study by Mohamed et al., (2010) found that there is little attention has been paid to designing ergonomically correct side-mounted desktop chairs for university students. Mihartescu et al., (2021) it was established that the most important feature of the workstation is ergonomic.

A previous study by Pereira et al., (2014) defines ergonomics is the science that offers a positive basis for the modern forms of production administration, reducing the incidence of pathologies. Also, a study by Eugene, (2017) defines that ergonomics as the study of the relationship between the workers and the working environment. According to Talapatra & Mohsin, (2020), tools that are not ergonomically fit may have an adverse effect on the health of users and ths can provide risk or hazard of causing harm.

Food et al., (1997) define ergonomics as the science involved in designing a workstation hence that it accommodates the worker. Additionally, a virtual figure representing the user is placed on the chair, in an appropriate posture, to check the ergonomics of the chair and to verify that the final design is stable enough to stand (Gross et al., 2011). In order to produce a user-friendly product that is suitable for the consumer, consideration of the ergonomic factor is taken into account (Hussin, 2009).

Ergonomics comes from the Latin *ergon* which means *work*, and *nomos* which means *natural law*. In addition to that, it is defined ergonomics as a systematic science to utilize the information about nature and humans' abilities and limitations to design a work system, since ergonomics is related to efficiency, optimization, health, safety, and comfort in the workplace or where they are placed. In general, ergonomics is a study of the system in which humans, work facilities, and their environment are correlated with each other in order to adapt to the work atmosphere and the people. In particular, the aim of studying ergonomics is to humanize humans (Wibowo & Mawadati, 2021).

According to Kalınkara et al., (2011), an ergonomically appropriate working environment designed by the needs of the workers is taken into account and determines the conditions that require minimum power for the task by minimizing the forces on the user. Though the design is simple, it still emphasizes ergonomics in the design (Mohd Idris & Esa, 2021). Ma et al., (2021) combined principal stress analysis, asymptotic stability, and ergonomics to design the Durotaxis Chair. Designing efficient ergonomic chairs and tables for students while some of them are available in the market, the new design should overcome all the disadvantages of existing ergonomic chairs and tables (Khan et al., 2022).

1.4 SOLIDWORKS simulation

According to a study by Madara et al., (2016) that used SOLIDWORKS, 2013 as an engineering, design and simulation tool. SOLIDWORKS software is essentially a three-dimensional (3D) solid model component system and an upgraded version of the computer-aided design (CAD) 3D software modelling system developed by the Windows operating system (Wu et al., 2019). To enable the manufacturability of furniture designs, joints must be added at places of intersections. However, for casual end-users, determining and drawing proper joint patterns can be a liability, even with the help of some design software (e.g., AutoCAD, SOLIDWORKS, UG, Inventor, Inkscape, and so forth) (Yan et al., 2023).

According to Baikerikar, (2017), the dogbone is designed similarly to the specifications stated in ASTM D638. These geometries were designed in SOLIDWORKS as solid continuous models. Furthermore, SOLIDWORKS software makes a theoretical analysis of the durability of the Chair Ladder product that has been designed (Mohd Idris & Esa, 2021). Additionally, the 3D model of the edamame picking device was established by SOLIDWORKS, which provided a solid foundation for the later finite element force simulation analysis (Wu et al., 2019).

According to Koç et al., (2011), the FEA application is an important engineering technique that was investigated with SOLIDWORKS/CosmosWorks system. In addition to that SOLIDWORKS Simulation uses a DoE-based optimization method (Systemes, 2021). Recent research (Conference & Studies, 2015) defines engineering analysis with SOLIDWORKS Simulation as an introductory text. Therefore, the focus is more on understanding FEA than presenting all software capabilities. The study used SOLIDWORKS simulation for FEA test.

Without using an optimization study, the best part of the design can be achieved only by expensive and time-consuming product development cycles. So typically, must first build the model in SOLIDWORKS CAD system, prototype the design, test the prototype in the field, evaluate the results of the field tests and modify the design based on the field test results. This process can continue until a satisfactory solution is reached. On the other hand, by using SOLIDWORKS modules for preliminary studies (SOLIDWORKS Simulation Xpress/Simulation/ Design Study) it can be accomplished tasks like testing the model using the computer rather than field tests, thus reducing cost, reducing time to market by reducing the number of product development cycles and optimize the designs by simulating concepts and scenarios before making final decisions (Iancu, 2017).

The 3D model has been built using SolidWorks Software. Nowadays, SOLIDWORKS environment is considered a powerful tool that helps designers to design products and attain their performance before the physical prototype stage. Moreover, SOLIDWORKS simulation model has been employed to test the frame of the wheelchair under the weight of the human body and the upper part of the wheelchair (Altalmas et al., 2013).

As stated by Iancu, (1844) SOLIDWORKS simulation/simulation express module "offers an easy-to-use. As described by IANCU & GUTSALENKO, (2019) when is used a simulation tool, the best part design can be achieved only by CAD and simulation product development cycles, thus saving expensive and time-consuming tests. In a classical manufacturing cycle are taken following steps: modelling the item in SolidWorks CAD system, prototyping of the design model, testing the prototype in the laboratory, evaluating the results of the field tests and if it's necessary, modifying the design based on the field test results.

According to SOLIDWORKS, (1995), SOLIDWORKS mechanical design automation software is a feature-based, parametric solid modelling design tool which takes advantage of the easy-to-learn Windows graphical user interface. Similarly, a previous study by Paper et al., (2013) introduced SOLIDWORKS is considered one of the most powerful tools to design and simulate mechanical designs and products.

1.5 Finite element analysis (FEA)

According to Starovoytova et al., (2016), the FEA is a computational technique used to obtain approximate solutions of boundary/field value problems in engineering. A recent study by Mahantesh et al., (2023) stated that the FEA is a method used to analyse the physical phenomena in solid and fluid mechanics, structural field and also for the solution of the field problems. Previous research by Haraga & Goantă, (2017) specified that the FEA application is an important engineering technique in the furniture industry nowadays.

Previous research by Miller, (1989) stated that FEMs are the most common analytical tool used to evaluate the strength design of furniture frames, and the resultant stiffness matrix structural analyses will pinpoint the weakness points in the structure. In addition to that the CAD system incorporates the complete design/redesign process, from detailed product drawing to strength and stability evaluation of furniture, by applying the FEA.

According to Mustafa, (2012), the first study of FEM in furniture design was in 1966. A study by Langová et al., (2019) is aimed at designing flexible chairs consisting of lamellae using FEA. Research by Hemaraju et al., (2019) identified that the FEA is the most widely used computational technique where a complex geometry is divided into a mesh that consists of elements represented by nodes at the corners. According to Fu et al., (2017), the FEA method gradually is applied to the structural design/redesign of the sewing furniture.

Most furniture frames are made up of structural elements called indeterminate frames, which makes it a rather tedious task to analyze the internal forces in the frame. However, using the FEA, it has been possible to overcome this issue (Hu et al., 2019). The required steps for FEA analysis, which is standardized by the engineering community and sometimes guided by the technical guidelines of the regulatory agencies, are elaborated to show that the FEA techniques are universal and thus acceptable in the international engineering community (Javidinejad & Ph, 2021).

According to Baikerikar, (2017), the FEA is a widely used analysis tool for various linear and nonlinear engineering problems (structural, vibrational, thermal etc.). Finite element analysis (FEA) is a numerical method for solving problems in engineering and mathematical physics. It's very useful for problems with complicated geometries, loadings, and material properties where analytical solutions can be obtained. FEA is the method of using virtual simulation technology to test how a product design reacts to physical effects including bending, heat, vibration, fluid flow, and other impacts (Mohd & Esa, 2021).

According to Wu et al., (2019) the unique advantage of the SOLIDWORKS software, that is, the FEA function to mesh the internal appearance structure of the sugarcane harvester drainage device. Previous research by Bryant et al., (2005) stated that the existing design tools primarily focus on the initial design phases, such as customer need gathering (e.g. quality function deployment), or on the later steps of design embodiment or detail design (e.g. design structure matrices, graph grammars, solid models, dynamic modelling, and FEA).

According to Simek & Sebera, (2010), the most suitable technologies for the field of furniture are found within Computer Aided Engineering (CAE), namely numerical simulations, FEA development and Computer Numerical Control (CNC) production. Recent studies related to the modelling and the analysis of furniture design are focused on using a process of parametric CAD modelling and FEA for achieving furniture pieces (Scurtu et al., 2015).

1.6 Purpose of the study

The purpose of this present study is to design and simulate an ergonomic sewing chair workstation for workers at garments manufacturing, REAL, Eldoret, Kenya.

2. Materials and methods

2.1 Simulation Methods of FEA Static Analysis

FEA is a significant computerized numerical method that provides approximate solutions for structural and thermal analysis in different application areas. Furthermore, to perform the FEA static simulation to get the results the following steps can be used as seen in Figure 1.

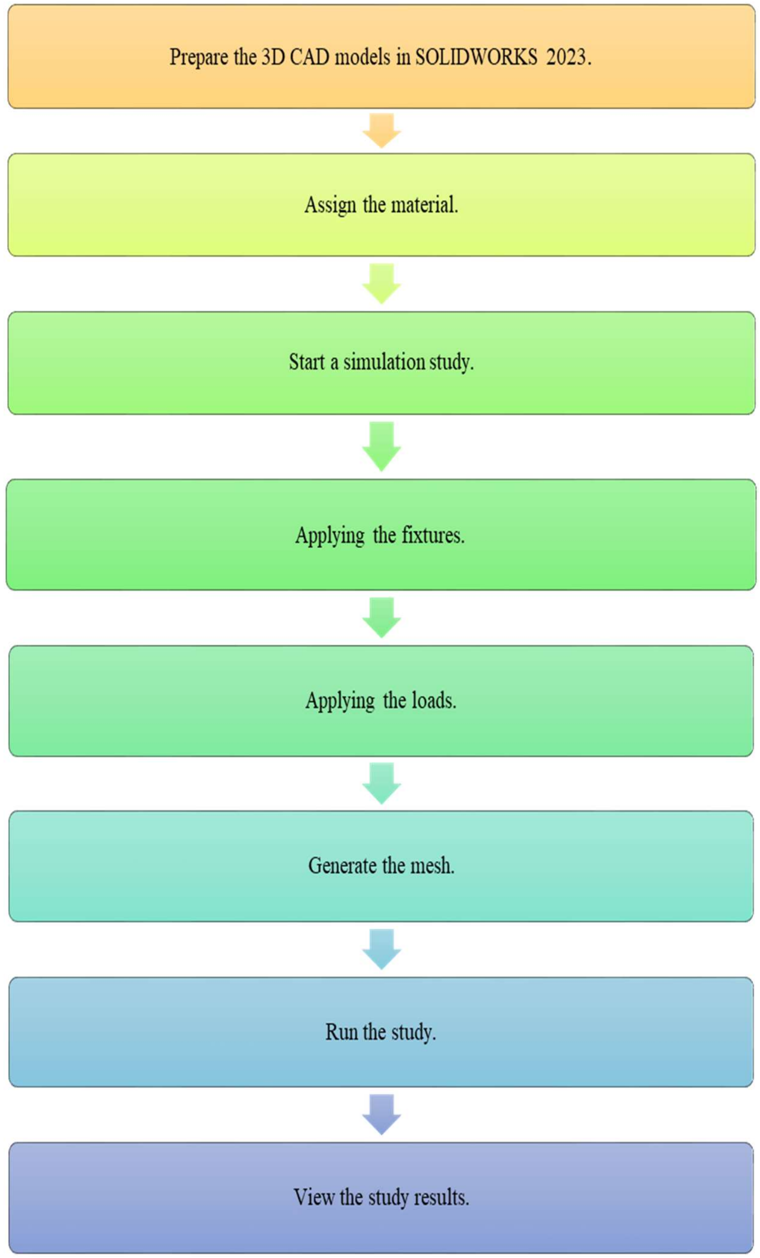
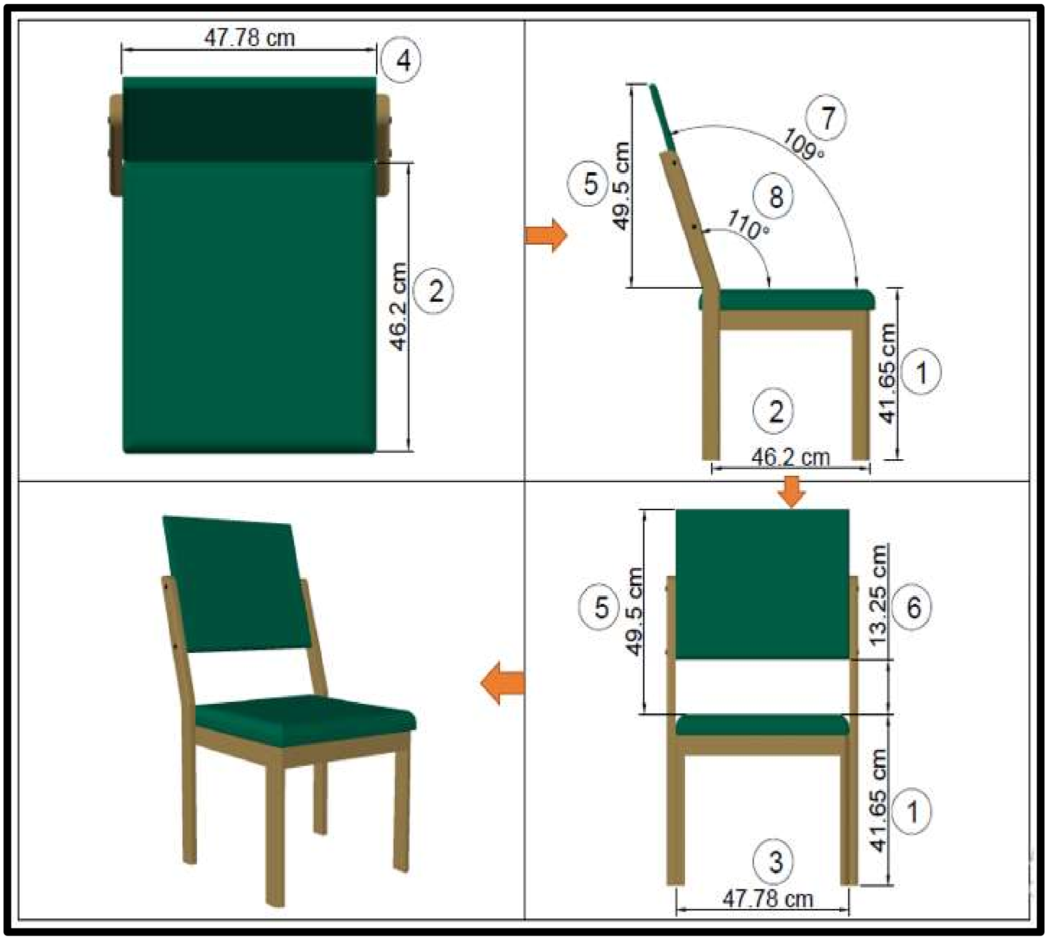


Figure 1: Main steps of the simulation models using FEA static analysis

2.1.1 Prepare the 3D CAD Model in SOLIDWORKS 2023

The model of the sewing chair was drawn and built using a part design in SOLIDWORKS 2023 as a 3D finite element analysis program based on the worker's (male and female) anthropometric data. This 3D CAD model was used for FEA as the simulation experimental. The proposed worker's sewing chair model is seen in Figure 2.



	Keys:
1	*Seat height.*
2	*Seat depth.*
3	*Seat width.*
4	*Back rest width.*
5	*Backrest height (Upper) above seat.*
6	*Backrest height (Lower) above seat.*
7	*Backrest angle.*
8	*Seat angle.*

Figure 2: The proposed workers' sewing chair model done by 3D SOLIDWORKS 2023

2.1.2 Assign the Material

The response of a part (sewing chair) model depends on the material assigned to the part. Besides, in the material dialog box, expand the class of materials and select a material then click apply. Additionally, the assigned material for the part design of the sewing workstation (sewing chair) as illustrated in Figure 3.

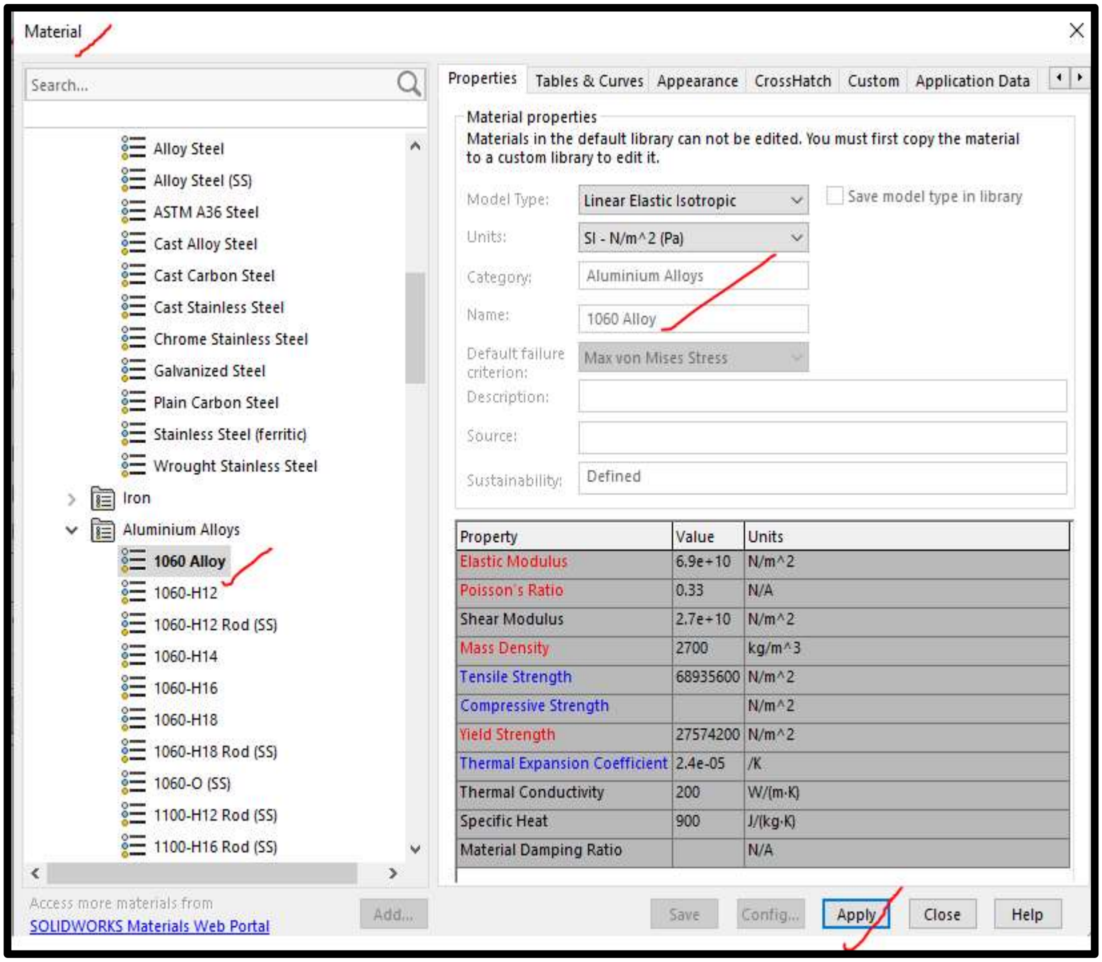


Figure 3: Assigning material for the part (sewing chair) model

3.1.2.1 Material Selection for FEA Test

According to recent studies by Starovoytova et al., (2016); and Madara et al., (2016) the properties for consideration of the materials selection were limited to: technical properties of materials (density, conductivity, strength, etc.); manufacturing of materials (easy to manufacture with existing manufacturing facilities, etc.); economic properties of materials (cost for material and production, availability, etc.) and; ecological properties of materials (recycle-ability, sustainability, etc.). Additionally, the materials selection was done according to Miller, (1989). Aluminium alloy was selected for the FEA test because is now the most widely used metal in the furniture industry due to its competitive cost, lightweight, corrosion-resistant, and excellent working properties, especially for the manufacture of metal chairs. In this context, metals continue to be the preferred material for sewing furniture due to their contemporary look. In addition, the FEA static analysis was employed on the sewing workstation (sewing chair) model to check its ability to stand under the weight of the human body. Table 1 shows the specifications of used materials.

Table 1: Specification of used material properties

Properties/Materials	Aluminium alloy 1060		References
	Value	Units	
Elastic modulus	6.9e + 10	N/m^2	Starovoytova et al., (2016); Kureshi et al., (2014); Madara et al., (2016) and Paper et al., (2013).
Poisson's ration	0.33	N/A	
Shear modulus	2.7e + 10	N/m^2	
Mass density	2700	Kg/ m^3	
Tensile strength	6.893e + 01	N/mm^2	
Yield strength	2.757e + 01	N/mm^2	
Thermal conductivity	200	W/(m.k)	
Specific heat	900	J/(kg.k)	

2.1.3 Start a Simulation Study

To start a simulation study for this research. Therefore, from the simulation toolbar in SOLIDWORKS simulation, the new study was selected then clicked ok on the static for starting a simulation study for the FEA test on the proposed sewing chair model as seen in Figure 4.

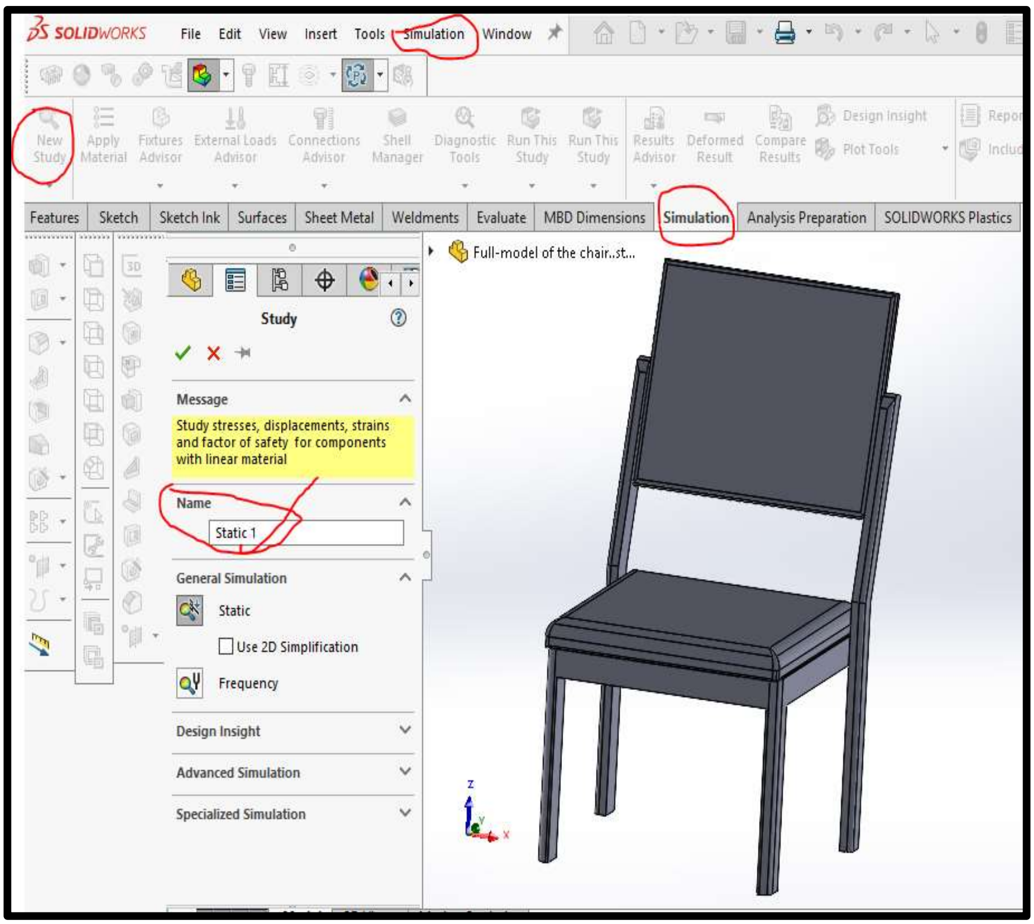


Figure 4: Starting a simulation study for the sewing chair model

2.1.4 Applying the Fixtures

In the simulation analysis, the first step is applied fixtures to faces or edges of the model part. However, in this present study, the fixtures were applied in five faces for the proposed sewing chair model as seen in Figure 5 as well as in the Table 2.

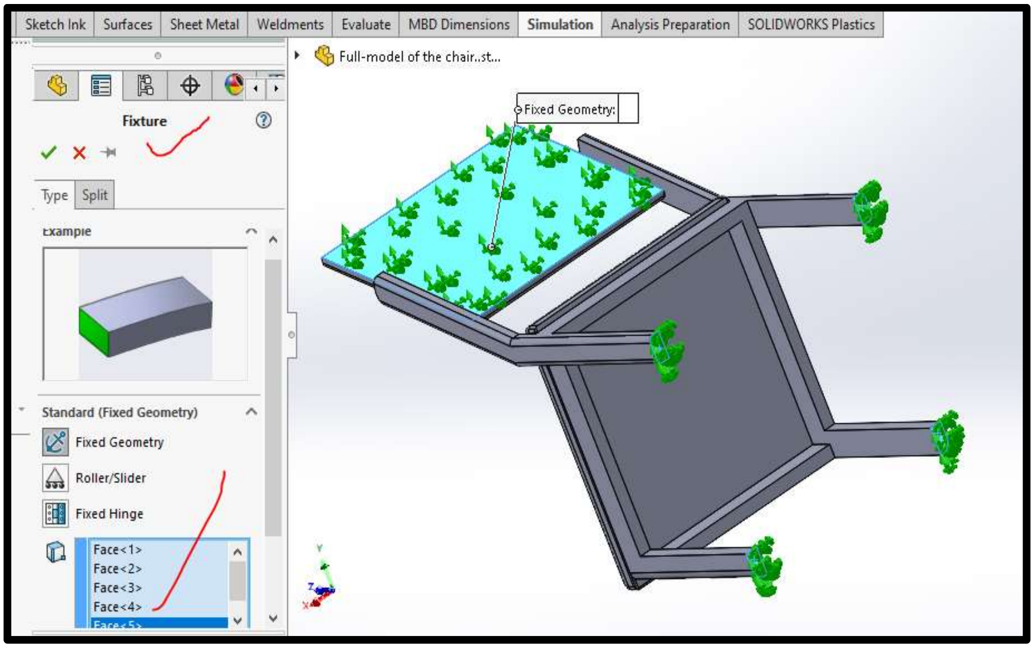
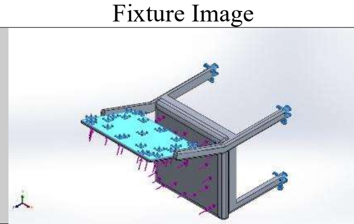


Figure 5: Appling fixtures in the five faces of the sewing chair model

Table 2: Appling fixtures in the sewing chair model

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

2.1.5 Applying the Loads

In SOLIDWORKS Simulation, the loads of the designed part can be either applied forces, pressure or both to face or edges of the model part. According to Mahantesh et al., (2023) the average human weight of 800 N or (82 kg) is applied at the base seat of the proposed sewing chair model while the average human weight of 150 N or (15 kg) is applied at the backrest seat of the proposed sewing chair model as seen in Figure 6 as well as in Tables 3 and 4.

Table 3: Loads acting on sewing workstation

SI. No	Parts	Load (N)	References
1	The base seat of the proposed sewing chair model	800	Mahantesh et al., (2023).
2	The backrest seat of the sewing chair model	150	

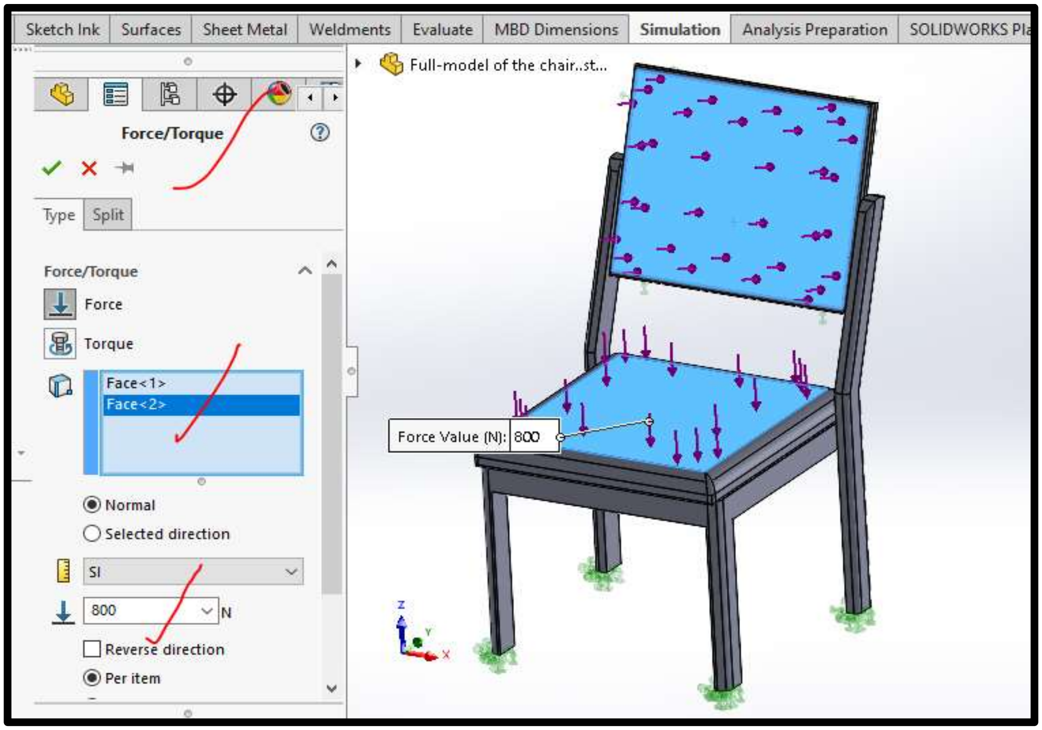
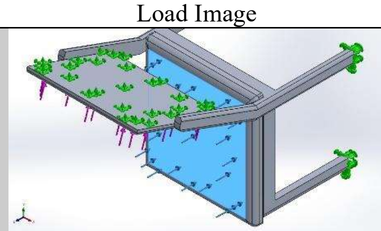
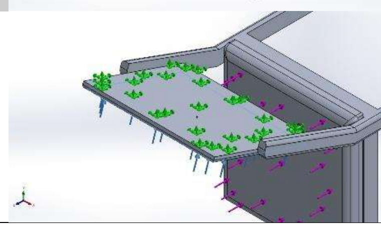


Figure 6: Applying the loads in the sewing chair model

Table 4: Applying the loads in the 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

2.1.6 Generate the mesh

The mesh was generated as seen in Figure 7 as well as in Table 5 as the element shape taken was tetra and quad with fine sizing. Additionally, the mashing generated information considered was: maximum element size is 54.0261 mm; minimum element size is 2.70131 mm; mesh quality is high; total nodes is 69620; total elements is 39657; maximum aspect ratio is 34.349; % of elements with aspect ratio < 3 is 98.8; percentage of elements with aspect ratio > 10 is 0.00504; percentage of distorted elements is 0 and time to complete mesh is 00:00:13 (hh:mm:ss).

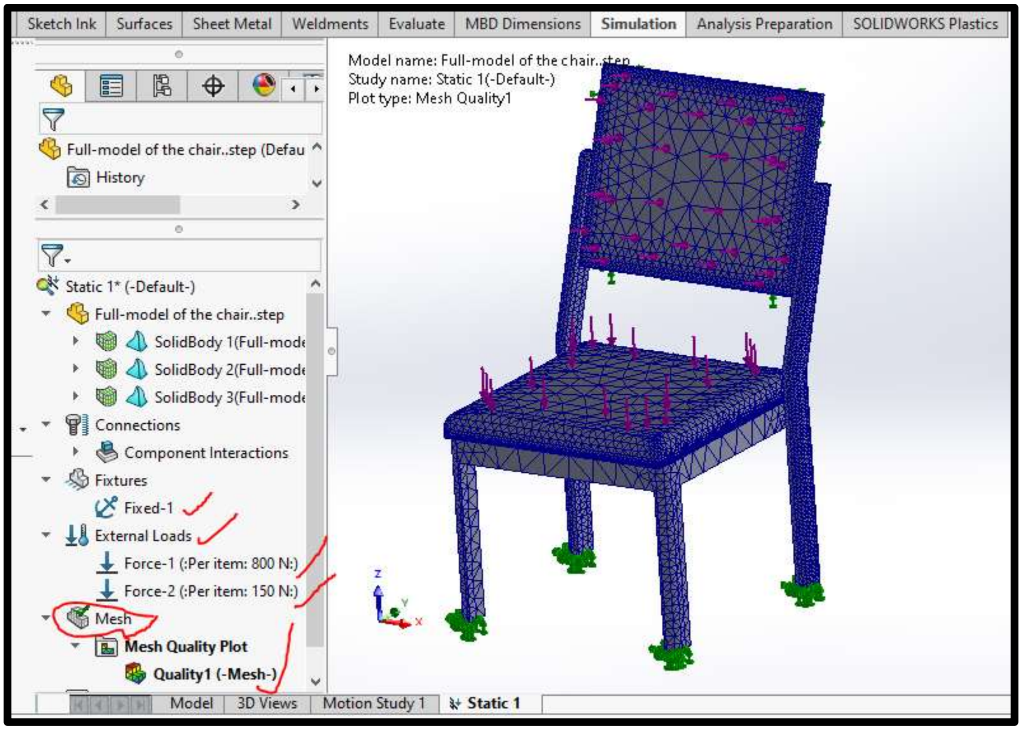


Figure 7: Mashing generated for the proposed sewing chair model

Table 5: Mashing generated information for the proposed 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

2.1.7 Run the Study

Simulation prepares the model for analysis and then calculates stress, displacements, strain and FOS. At this stage, it's done a static analysis by FEA of the studied part, with default settings for the type of finite element and mesh density. For these elements can be used the default settings or changed settings, as described by Iancu, (1844), (2017); and Iancu & Gutsalenko, (2019). These settings were used for the simulation and analysis as seen in figure 8. Moreover, linear static analysis is run on the proposed sewing chair model. This is to determine the maximum stress and strain on the proposed sewing chair model. This is because, before fabricating some design we need to know the performance of the object that needs to be fabricated. It is to avoid something wrong happening for example fabricating an object without knowing the performance may lead to a waste of energy or waste of money as maybe the object cannot become as desired. Hence, running a simulation test on the design in SOLIDWORKS software may prevent unwanted events from happening.

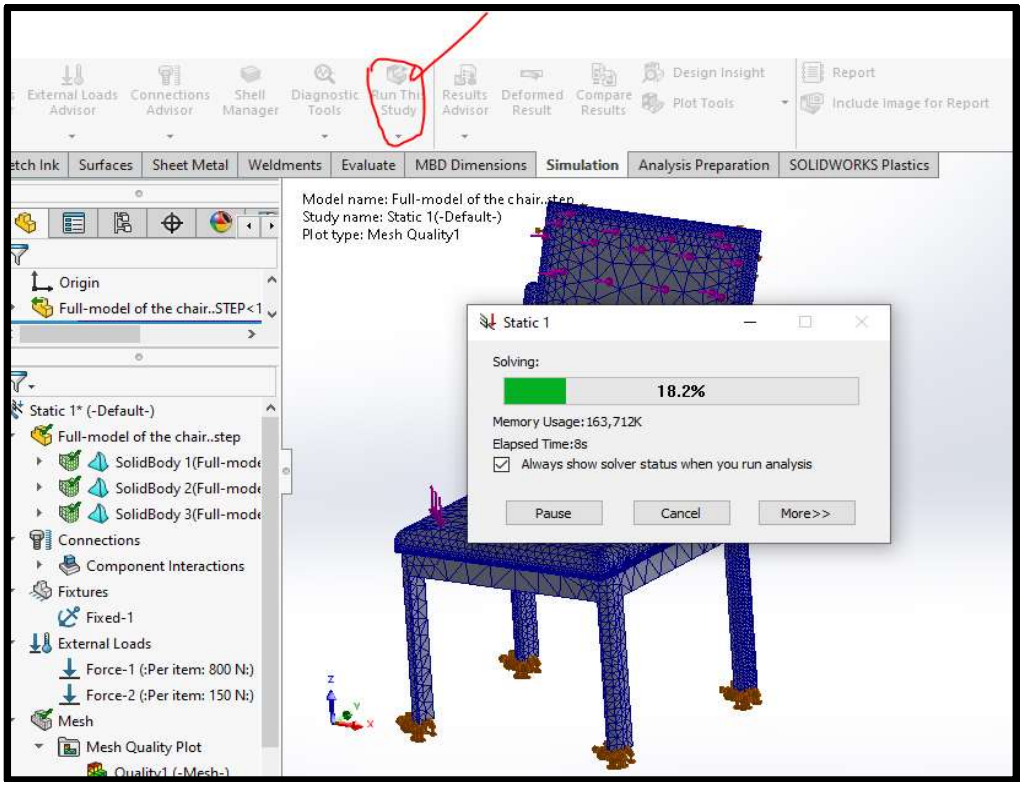


Figure 8. Running the static analysis for the proposed sewing chair model by FEA

2.1.8 View the Study Results

After running a study, the results were viewed for the sewing workstation (proposed sewing) model as stress, strain, displacement and FOS results. Besides, figure 9 shows the viewing the study results for FEA static analysis.

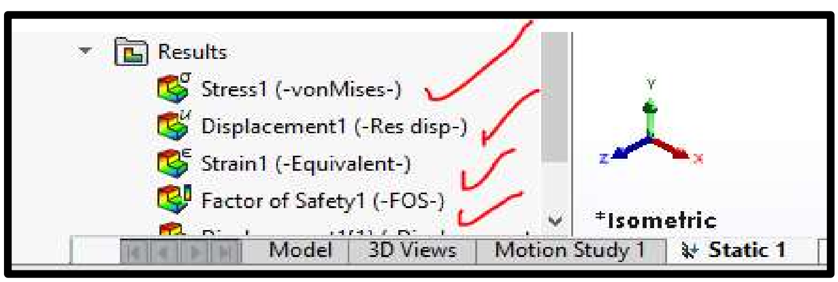


Figure 9: Viewing the study results

3. Results and Discussion

3.1 Simulation Results of FEA Static Analysis for the Proposed Sewing Chair

A static simulation study was done on the proposed sewing chair model with a deformation scale of 30,050.2 to ensure the capability of the model to stand under the weight of the human body. Additionally, the proposed sewing chair was analyzed through FEA static analysis test to check its ability to stand under the weight of the human body. The 800 N (82 kg) external force was applied at the upper side of the proposed sewing chair and 150 N (15 kg) was applied at the backrest of the sewing chair. In addition, the FEA static test has been done using aluminum alloy 1060 with the elastic modulus: 6.9e + 10 N/m^2; yield strength: 2.757e + 01 N/mm^2; tensile strength: 6.893e + 01 N/mm^2; specific heat; 900 J/(kg.k); Poisson's ratio: 0.33; mass density: 2700 kg/m^3; thermal conductivity: 200 W/(m.k) and shear modulus: 2.7e+10 N/m^2 for the proposed sewing chair model to check the ability to stand under the weight of the human body.

3.1.1 Results of Stress Analysis of the Proposed Sewing Chair Model

The stress analysis results for the sewing chair are shown in Figure 10 and Table 6, as the value of maximum and minimum stress for the proposed sewing chair which acts on the seat and the backrest. The maximum value for stress at the seat is 7.175e – 01 N/mm^2, node: 67581 and the minimum stress is 1.414e – 05 N/mm^2, node: 48336. Therefore, the proposed sewing chair redesign value for maximum stress does not exceed the yield strength of the selected material which is 2.757e + 01 N/mm^2, which was below the assigned safety level. Thus, the proposed sewing chair model part will not break or fail under applied external loads.

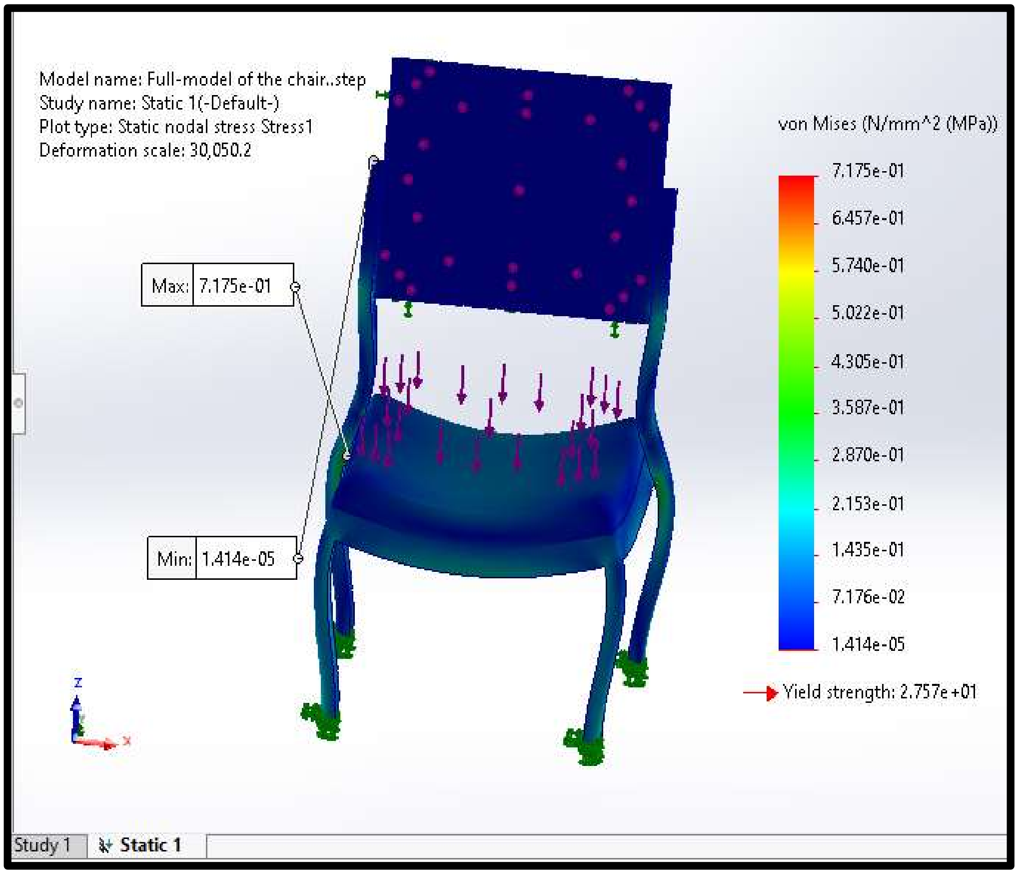


Figure 10: Results of stress analysis of the proposed sewing chair mode

Table 6: Results of stress analysis on proposed sewing chair redesign

Linear static analysis	Value/Units
Yield strength for the selected material	2.757e + 01 N/mm^2
Max stress on the sewing chair model	7.175e – 01 N/mm^2 Node: 67581
Min stress on the sewing chair model	1.414e – 05 N/mm^2 Node: 48336

3.1.2 Results of Displacement Analysis of the Proposed Sewing Chair Model

The displacement analysis results for the proposed sewing chair model are shown in Figure 11 and Table 7, as the value of maximum and minimum displacement for the sewing chair which acts on the seat and the backrest. The maximum value for displacement at the seat is 3.209e – 03 mm, node: 26013 and the minimum stress is 1.000e – 30 mm, node: 36303. Therefore, the proposed sewing chair model value for the maximum deformation is very small, it is 0.03209 mm, which was below the assigned safety level. Thus, the maximum displacement achieved when the proposed sewing chair model was subjected to the loads specified, was barely noticeable and hence the part was decided to be acceptable to work in those conditions as specified.

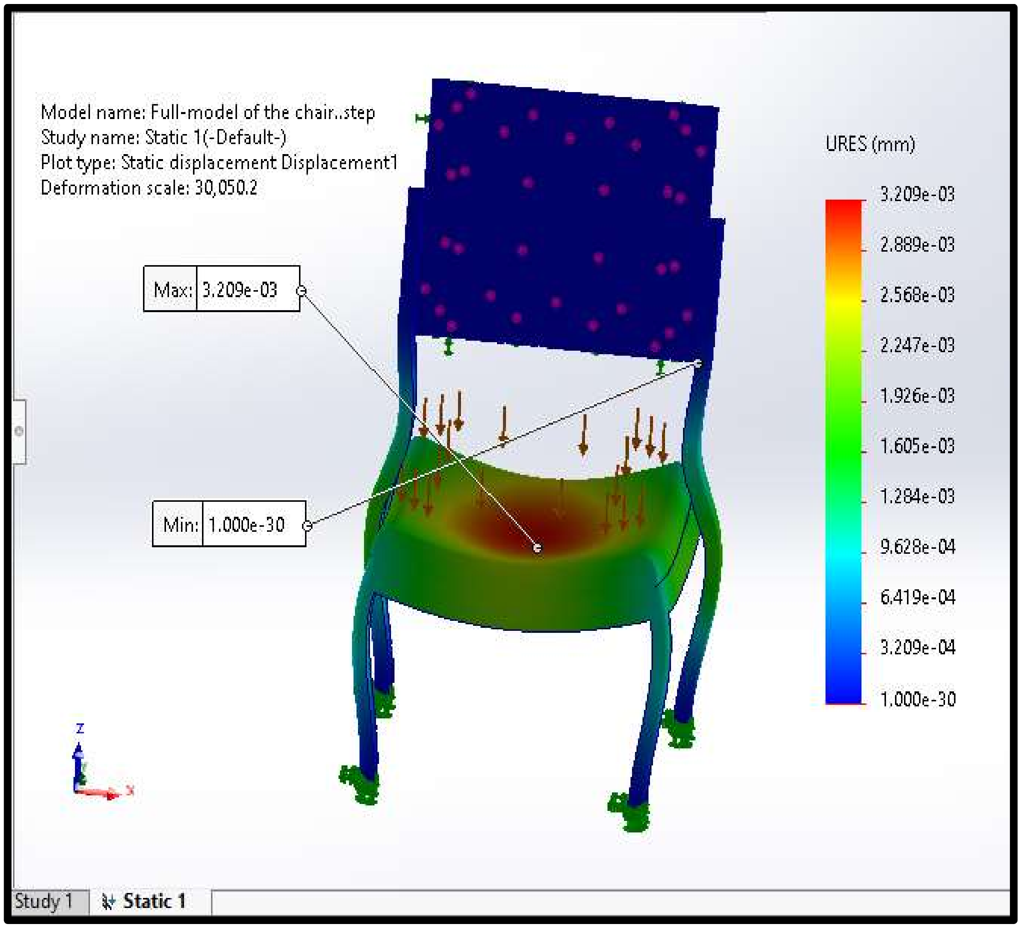


Figure 11: Results of displacement analysis of the proposed sewing chair model

Table 7: Results of displacement analysis on the proposed sewing chair model

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

3.1.3 Results of Strain Analysis for the Proposed Sewing Chair Model

The strain analysis results for the proposed sewing chair model are shown in Figure 12 and Table 8, as the maximum value of the strain at the seat of the chair is 6.258e - 06; element: 35287 and the minimum strain is 1.502e - 10; element: 27300. Therefore, the maximum strain value occurs in the middle of the seat. It shows the elongation occurs when the seat is applied with the load. Since the value of strain does not exceed the value of tensile strength of the selected material, which is 6.893e + 01 N/mm^2, therefore, the seat model will not break or fail during this load.

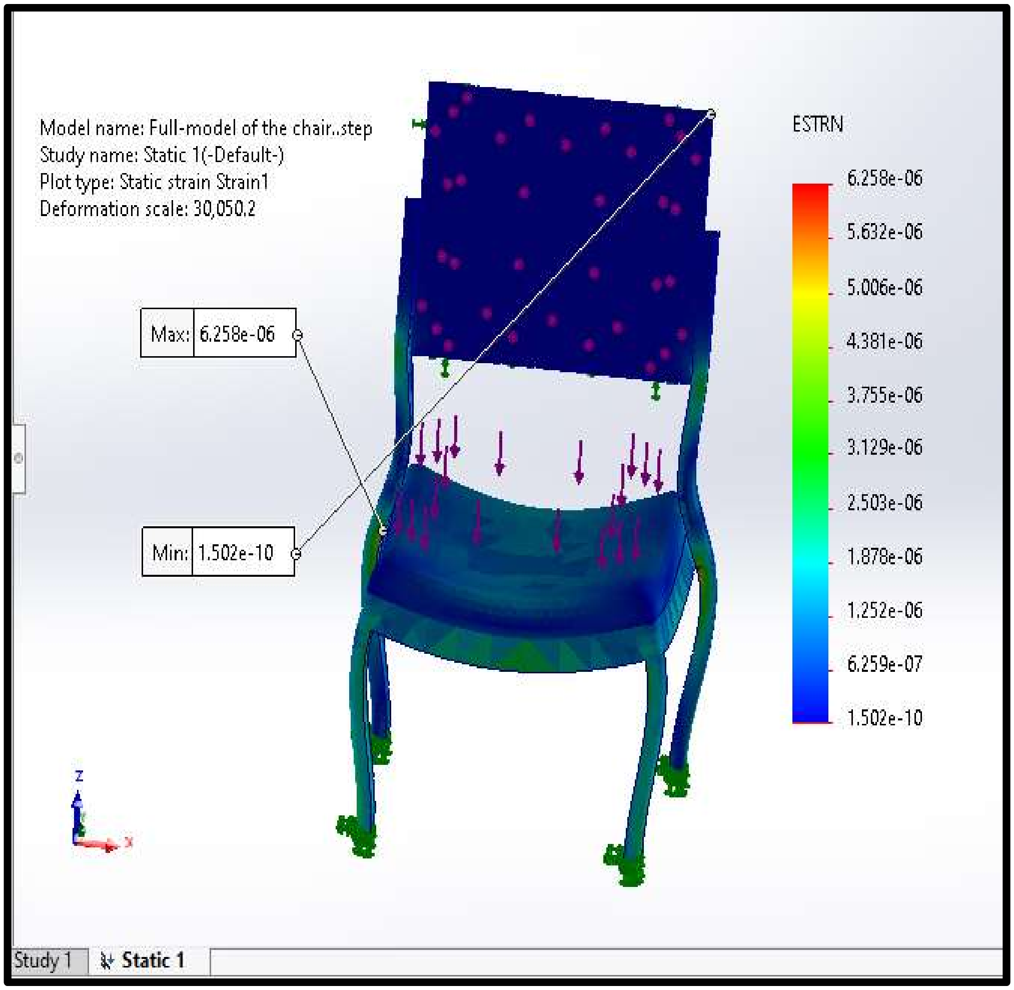


Figure 12: Results of strain analysis of the proposed sewing chair

Table 8: Results of strain analysis on the proposed sewing chair model

Linear static analysis	Value/Units
Tensile strength for the selected material	6.893e + 01 N/mm^2
Max strain on the sewing chair model	6.258e – 06; Element: 35287
Min strain on sewing chair model	1.502e – 10; Element: 27300

3.1.4 Results of FOS for the Proposed Sewing Chair Model

The FOS analysis results for the proposed sewing chair model were shown in figure 13 and table 9, as the maximum value of the FOS at the seat of the chair is 3.000e + 00; node: 1 and the minimum FOS is 3.000e + 00; node: 1. Therefore, the minimum FOS distribution value of 3 that means the model needs 3 times of loads applied to deform the selected materials, which is surely safe product and will not brake or failure during the applied loads.

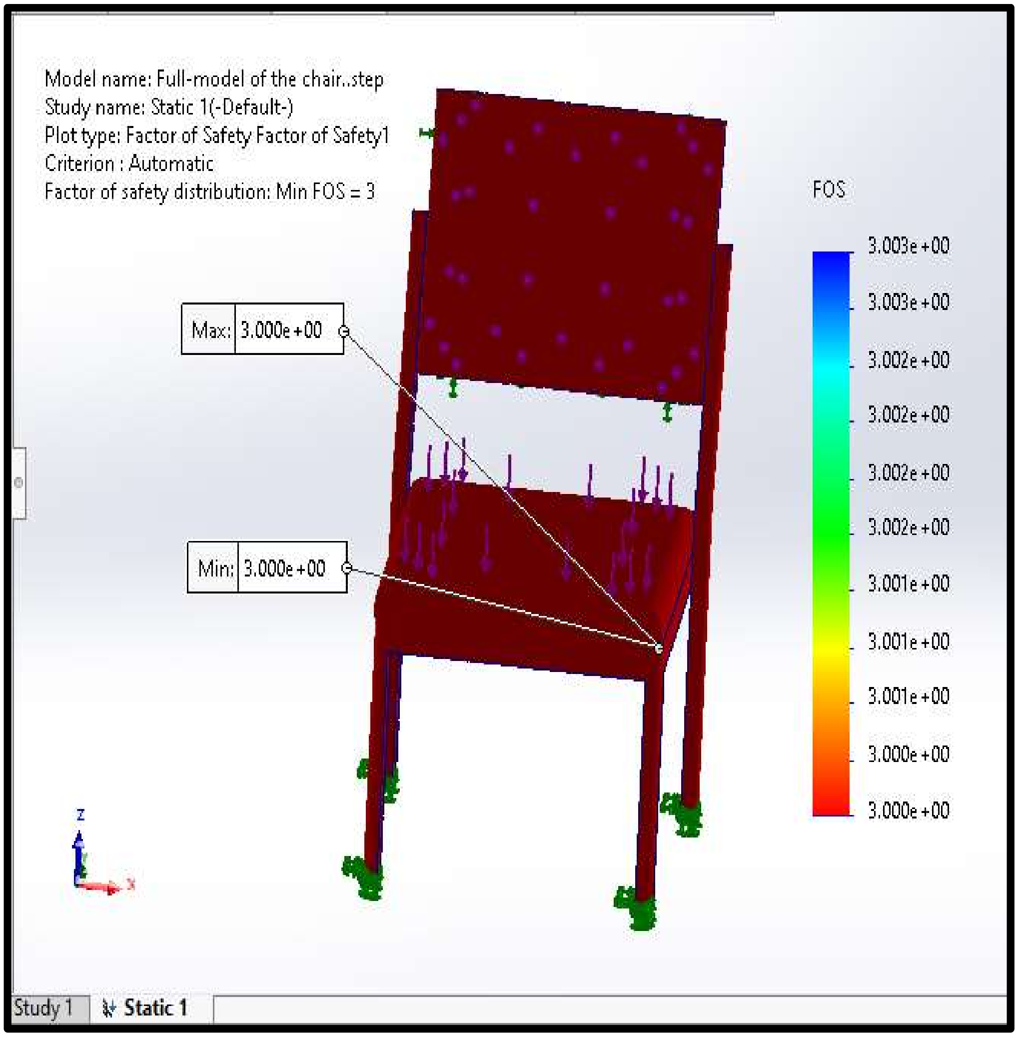


Figure 13: Results of FOS analysis on the proposed sewing chair

Table 9: Results of FOS analysis on proposed sewing chair model

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

4.0 Conclusion

In conclusion, the objective of this study was to design and simulate an ergonomically sewing chair workstation for workers in garments manufacturing. The FEA results were showed that aluminium model successfully passed the test, according to the due to the criteria considered in this study which included: maximum stress (7.175e-01 N/mm^2) which did not exceed the material yield strength. In addition, the maximum displacement (3.209e–03 mm), and thus, the maximum deformation (0.03209 mm), was also established to be below the assigned safety level. It was further established that the maximum strain of 6.258e-06 was within the acceptable limits, which implied that the model will not break or fail during the applied loads. Moreover, the minimum FOS distribution value of 3 established in this study, implied that the model needs 3 times of loads applied to deform the selected material, which can be considered as safe and acceptable for ergonomically fit sewing chairs for garment manufacturing workers. Therefore, the study can be extended by fabricating and manufacturing the proposed sewing chair model and validating the sewing chair design by experimental study.

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Conflict of interest
The authors declare that there is no conflicts of interest.

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References
Adeyemi, A. J., Ojile, P., Abdulkadir, M., & Lasisi, O. I. (2019). Effect of redesigning school furniture based on students' anthropometry in North-West Nigeria. Advances in Intelligent Systems and Computing, 826, 714–722. https://doi.org/10.1007/978-3-319-96065-4_75

Ahmed, F. (2018). Improving Workplace Safety through Ergonomic Intervention- A Case Study of a Readymade Garment Industry. Bangladesh University of Engineering & Technology. 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/

Altalmas, T. M., Ahmad, S., Aula, A., Akmeliawati, R., & Sidek, S. N. (2013). Mechanical design and simulation of two-wheeled wheelchair using solidworks. IOP Conference Series: Materials Science and Engineering, 53(1). https://doi.org/10.1088/1757-899X/53/1/012042

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). https://doi.org/10.1063/5.0000602

Avadanei, M. L., Olaru, S., Dulgheriu, I., Ionesi, S. D., Loghin, E. C., & Ionescu, I. (2022). A New Approach to Dynamic Anthropometry for the Ergonomic Design of a Fashionable Personalised Garment. Sustainability (Switzerland), 14(13), 1–24. https://doi.org/10.3390/su14137602

Baikerikar, P. (2017). Comparison of As-built FEA Simulations and Experimental Results for Additively Manufactured Dogbone Geometries. Recommended Citation. https://tigerprints.clemson.edu/all_theses

Bryant, C. R., Stone, R. B., McAdams, D. A., Kurtoglu, T., & Campbell, M. I. (2005). Concept generation from the functional basis of design. Proceedings ICED 05, the 15th International Conference on Engineering Design, DS 35(April 2015).

Burns, C. M., & Vicente, K. J. (2000). A participant-observer study of ergonomics in engineering design: - rules, types, and worlds. Applied Ergonomics, 31(1), 73–82.

Chan, J., Janowitz, I., Lashuay, N., Stern, A., Fong, K., & Harrison, R. (2002). Preventing musculoskeletal disorders in garment workers: Preliminary results regarding ergonomics risk factors and proposed interventions among sewing machine operators in the San Francisco Bay Area. Applied Occupational and Environmental Hygiene, 17(4), 247–253. https://doi.org/10.1080/10473220252826547

Conference, I., & Studies, I. (2015). 통합시청률 조사 패널 참여에 영향을 미치는 요인에 관한 연구 Table of Contents 연구 배경. Social Media in India 2014, 1(September), 0–11.

Eladly, A. M., Abou-Ali, M. G., Sheta, A. M., & EL-Ghlomy, S. H. (2020). A flexible ergonomic redesign of the sewing machine workstation. Research Journal of Textile and Apparel, 24(3), 245–265. https://doi.org/10.1108/RJTA-10-2019-0050

Erdil, Y. Z., Haviarova, E., & Eckelman, C. A. (2004). Product Engineering and Performance Testing in Relation. Wood and Fiber Science, 36(3), 411–416.

Esmaeel, A., & Order, K. S. (2017). INTERNATIONAL STANDARD technological design —. 2017.

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

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. https://doi.org/10.1201/9781003221968-5.

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. https://doi.org/10.7176/ISDE/14-1-06.

Etemadi Nejad, S., Hosseininejad, E., Yazdani Charati, J., Ghaempanah, F., Yousefi Chemazkati, M., Ahmadi, mojtaba, & Amani, A. (2020). Effect of Workstation Designed for Sewing, on Neck and Shoulder Muscles of Users. Journal of Ergonomics, 7(4), 12–20. https://doi.org/10.30699/jergon.7.4.12

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. https://doi.org/10.1063/1.5002052

Food, T. A., States, U., Haploscopic, C., Chromagen, T., Harris, D., Cantor, D., Cantor, S., Optics, P., Swarbrick, H., Wales, N. S., & D-, F. M. (1997). Fact sheet Fact sheet. 1–3.

Fu, Y., Fang, H., & Dai, F. (2017). Study on the properties of the recombinant bamboo by finite element method. Composites Part B: Engineering, 115, 151–159. https://doi.org/10.1016/j.compositesb.2016.10.022

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.

Gopura, R., & Amarasena, K. (2008). Design of an ergonomically efficient chair. 14th ERU Symposium, January 2008, 12–14.

Gross, M. 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.

H, A. B., Rao Kvs, R., & Subramanya, K. N. (2014). Ergonomic Evaluation of the Work Stations in a Garment Manufacturing Industry-an Exploratory Study. International Journal of Mechanical And Production Engineering, 24, 2320–2092.

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. https://doi.org/10.3233/WOR-151991

Halpern, C. A., & Dawson, K. D. (1997). Design and implementation of a participatory ergonomics program for machine sewing tasks. International Journal of Industrial Ergonomics, 20(6), 429–440. https://doi.org/10.1016/S0169-8141(96)00070-4

Haraga, G., & Goantă, A. M. (2017). FEA analysis and design optimization for a multifunctional piece of furniture. MATEC Web of Conferences, 112. 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. https://doi.org/10.2507/IJSIMM16(1)1.355

Harrison, R. J., Yu, F., Chan, J., & Rempel, D. M. (2008). A Randomized Controlled Trial of Chair. April. https://doi.org/10.1097/JOM.0b013e318163869a

Hemaraju, S., Yermal, K., & Archana, M. (2019). Ergonomic Evaluation through Digital Human Modelling: A Review. Researchgate.Net, December. https://sci-hub.ren/https://www.researchgate.net/profile/Sanjana-Hemaraju/publication/337927653_Ergonomic_Evaluation_through_Digital_Human_Modelling_A_Review/links/5df46e014585159aa47bfec2/Ergonomic-Evaluation-through-Digital-Human-Modelling-A-Review.pdf

Hu, W., Liu, N., & Guan, H. (2019). Optimal design of a furniture frame by reducing the volume of wood. Drewno, 2019(204). https://doi.org/10.12841/wood.1644-3985.275.12

Hussin, M. R. (2009). DESIGN AND FABRICATION OF FOLDING TABLE MOHD ROSDI BIN HUSSIN A report submitted in fulfilment of the requirement for the award of the Diploma of Mechanical Engineering Faculty of Mechanical Engineering Universiti Malaysia Pahang NOVEMBER 2009. November, 1–24.

Iancu, C. (1844). ABOUT OPTIMIZATION FEATURE ON SOLIDWORKS SIMULATIONEXPRESS MODULE. 2, 78–84.

Iancu, C. (2017). About optimization design study on solidworks. 1, 199–206.

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

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.

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.

Khan, F., Ghanem, W. S., & Garaniya, V. (2022). Advances in Behavioral Based Safety. In Advances in Behavioral Based Safety. https://doi.org/10.1007/978-981-16-8270-4

Koç, K. H., Kizilkaya, K., Seda Erdinler, E., & Korkut, D. S. (2011). The use of finite element method in the furniture industry. African Journal of Business Management, 5(3), 855–865. https://doi.org/10.5897/AJBM10.551

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

Langová, N., Réh, R., Igaz, R., Krišt'ák, L., Hitka, M., & Joščák, P. (2019). Construction of wood-based lamella for increased load on seating furniture. Forests, 10(6). https://doi.org/10.3390/f10060525

Leilanie Del Prado-Lu, 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. https://doi.org/10.1080/10803548.2004.11076618

Li, G., Haslegrave, C. M., & Corlett, E. N. (1995). Factors affecting posture for machine sewing tasks. The need for changes in sewing machine design. Applied Ergonomics, 26(1), 35–46. https://doi.org/10.1016/0003-6870(94)00005-J

M. I. Ali, M. S. Rahman, M.S. Parvez, A. S. M. 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.

Ma, J., Li, Z., Zhao, Z. L., & Xie, Y. M. (2021). Creating novel furniture through topology optimization and advanced manufacturing. Rapid Prototyping Journal, 27(9), 1749–1758. https://doi.org/10.1108/RPJ-03-2021-0047

Mahantesh, M. M., Rao, K. V. S. R., Chandra, A. C. P., Vijayakumar, M. N., Nandini, B., Prasad, C. 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. https://doi.org/10.1007/s12008-023-01383-9

Mihartescu, A.-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.

Miller, R. K. (1989). Furniture Manufacturing. In Industrial Robot Handbook. https://doi.org/10.1007/978-1-4684-6608-9_75

Mohamed Thariq, M. G., Munasinghe, H. P., & Abeysekara, J. D. (2010). Designing chairs with mounted desktop for university students: Ergonomics and comfort. International Journal of Industrial Ergonomics, 40(1), 8–18. https://doi.org/10.1016/j.ergon.2009.10.003

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

Mukulu Ndeleva, B. (2017). ANTHROPOMETRY OF THE DISTAL FEMUR IN A KENYAN POPULATION AND ITS CORRELATION WITH TOTAL KNEE REPLACEMENT IMPLANTS. In EAOJ (Vol. 11). https://www.researchgate.net/publication/325416551

Mustafa Hilmi ÇOLAKOĞLU. (2012). Finite element analysis of wooden chair strength in free drop. International Journal of the Physical Sciences, 7(7), 1105–1114. https://doi.org/10.5897/ijps11.1229

Obinna, F. P., Sunday, A. A., & Babatunde, O. (2021). Ergonomic assessment and health implications of classroom furniture designs in secondary schools: a case study. Theoretical Issues in Ergonomics Science, 22(1), 1–14. https://doi.org/10.1080/1463922X.2020.1753259

Oyewole, S. A., Haight, J. 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. https://doi.org/10.1016/j.ergon.2010.02.002

Pagnan, A. S., & Câmara, J. J. D. (2012). Ergonomics analysis of the productive environment of fashion clothing firm in Belo Horizonte- MG. Work, 41(SUPPL.1), 1261–1267. https://doi.org/10.3233/WOR-2012-0311-1261

Paper, C., Altalmas, T. M., Ahmad, S., Akmeliawati, R., & Sidek, N. (2013). Mechanical design and simulation of Two-Wheeled wheelchair using solidworks. May 2015. https://doi.org/10.1088/1757-899X/53/1/012042

Pascual, A. I., Högberg, D., Lämkull, D., Luque, E. P., Syberfeldt, A., & Hanson, L. (2021). Optimization of Productivity and Worker Well-Being by Using a Multi-Objective Optimization Framework. IISE Transactions on Occupational Ergonomics and Human Factors, 9(3–4), 143–153. https://doi.org/10.1080/24725838.2021.1997834

Patil, G. G., Yadav, R., Nadiger, V. G., Raichurkar, P. P., Chandrakar, K., & Chandurkar, P. (2017). Textile apparel industry: A responsibilty towards manpower. Colourage, 64(6), 38–46.

Pereira, J. O., Schlosse, J. F., Souza d'Arisbo, D. de, Silva, S. de L., Opazo, M. A. 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. https://doi.org/10.5897/ajar2014.8948

Ramdass, K., & du Plessis, H. (2007). the Application of Ergonomic Research Principles for Workstation Enhancement of Apparel Machinists. FLUX : Design Education in a Changing World, 2007, 1–20.

Realyvásquez-Vargas, A., Arredondo-Soto, K. C., Blanco-Fernandez, J., Sandoval-Quintanilla, J. D., Jiménez-Macías, E., & García-Alcaraz, J. L. (2020). Work standardization and anthropometric workstation design as an integrated approach to sustainableworkplaces in the manufacturing industry. Sustainability (Switzerland), 12(9). https://doi.org/10.3390/su12093728

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

Shah, Z. 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.

Sheta, A., Abou-Ali, M. G., El-Gholmy, S. H., & Eladly, A. 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. 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.

SolidWorks. (1995). Fundamentals of 3D Design and Simulation. www.solidworks.com/edureseller.

Starovoytova, D., Starovoytova Madara, D., Kiptoo Arusei, D., & Njuguna Njoroge, M. (2016). Design simulation and analysis of manual block-making machine. 7(7). www.iiste.org

Starovoytova Madara, D., Namango, S. S., & Arusei, D. (2016). Innovative Conceptual Design of Manual-Concrete-Block- Making-Machine. Online), 7(7), 2222–1727.

Syduzzaman, M., & Golder, A. S. (2015). Apparel analysis for layout planning in sewing section. International Journal of Current Engineering and Technology, 5(3), 1736–1742.

Systemes, D. (2021). SolidWorks Software. Solidworks, 9–11. https://www.solidworks.com/es

Taifa, I. W., & Desai, D. A. (2017). IndiaAnthropometric measurements for ergonomic design of students' furniture in. Engineering Science and Technology, an International Journal, 20(1), 232–239. 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.

Ulijaszek, S., & Komlos, J. (2010). From a history of anthropometry to anthropometric history. Human Variation: From the Laboratory to the Field, 183–197. https://doi.org/10.1201/9781420084740

Wibowo, A. 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). https://doi.org/10.1088/1755-1315/704/1/012022

Wu, D., Zhang, Z., & Wang, Z. (2019). Application research of solidworks in modeling of straw carbonization preparation plant. Journal of Physics: Conference Series, 1303(1). https://doi.org/10.1088/1742-6596/1303/1/012048

Yadav, R., Budhrani, B. P., C Balani, P., & S, P. (2017). Anthropometric and Ergonomic Compatibility of Tractor Workplace Design. Journal of Ergonomics, 07(S6), 1–7. https://doi.org/10.4172/2165-7556.1000.s6-001

Yan, W., Zhao, D., & Mehta, A. (2023). Fabrication-aware design for furniture with planar pieces. Robotica, 41(1), 48–73. https://doi.org/10.1017/S0263574722000443