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Design and Fabrication of Multipurpose Step Stool for Workshop

Alia Mazlan [1], Alias Mohd [1,*], Zahari Deraman [1]

[1] University College TATI, Jalan Panchur, Kampung Teluk Kalong, 24000, Kemaman, TERENGGANU
*Corresponding author: aliasmohd@uctati.edu.my

KEYWORDS

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ABSTRACT

A step stool is a product that offers comfortable work platforms in difficult-to-reach areas. It assists the user in achieving the ideal working height. The idea to design and fabricate a multipurpose step stool for workshop is come from the current situation at UC TATI FTK's Workshop where the student only used a wooden pallet to step and reaching the height of milling machine for setting purposes. There is many limitations and lack of safety on the pallet used and the new product must be produced to overcome these issues. The wooden pallet used is not safe and the weight is quite heavy, required a lot of space and serves only single purpose. To design and fabricate this multipurpose step stool, the existing product must be compared with the existing in the market in terms of design and function before the new concept is introduced. The concept of design comprises the idea how to design with considering safety, size, multipurpose function and small space required for storage. The whole of the project involved various methods such as concept design, analyzing and fabrication process. Analysis will be done with Finite Element Analysis (FEA).

1.0 INTRODUCTION

There are various ladders available in the market, but each is built for a particular purpose. It is important to choose the appropriate device for our intended use because it will assist in avoiding causes of accidental injuries. Hence, it was identified that there is need to design and fabricate such a multipurpose step stool that can be used for various purposes in workshop. For hard-to-reach positions, a step stool offers a comfortable work platform. The use of a step stool helps the user to reach the optimal working height (Thomas W. Parker, 2016). Step stools usually have one or two steps with a base. The platform allows the user more freedom to securely move around while standing on the platform in accessing a desired higher location, with the step or steps providing access to the platform. It is important for the user's protection to make a step stool as resistant to different types of loads on the legs as possible. Provide multiple purposes or function is a preferred feature of design for restricted places and must make the user feel that the product is strong and reliable. This project aims to resolve a problem at the UC TATI workshop where some student especially female students with different heights are having trouble to

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setting and clamp the cutting tool on milling machine. Student usually use wood pallet to step on it which requires more time and energy.

Pallet injuries are common in industrial and warehouse settings because people often misplace them or use them as stepping stools. The pallet is described by the MH1-2016 standard as a compact, horizontal, rigid, composite platform that is used as a base, storing, handling, and transporting goods as a unit load, often with superstructure (Rick Leblang, 2020). Many employees were injured because they did not see the pallet or were unaware that stepping on it might cause it to break. If someone run a warehouse and keep the goods on pallets, they may not realize that they are exposing themself to one of the most popular workplace hazards. Pallet-related accidents are most common when users trip on them, step on them, walk on them, or fall on them (Nils Wright, 2017). To reach something up high, workers will sometimes stand on a wooden pallet for help. To address this problem, a single product must be developed and produced to meet the needs of students at workshop which is multipurpose step stool. Step stools resemble a stool with wide step surface and are available in a wide range of sizes, styles, functions, and concepts.

Multipurpose objects are artefacts that have many purposes. The abundance of multipurpose goods on the market poses intriguing questions about the ideal consumer desires that determine whether such products succeed or fail (Viswanathan et al., 2017). In the field of manufacturing engineering products, design plays an important role in geometrical aspects such as scale, shape, and user convenience. Design is the process of thought and planning in order to give things form in such a way that they can be manufactured, used, and eventually destructed. Design has traditionally been thought of as either a product or a process (Talke et al., 2009). Flexible features in the product's design and development phases affect flexible features in the product's usage phases (özçelik, Özer, 2016). As an example, a multipurpose wooden table is a table that can be used as a weapon, a chair, a comfort chair, a tea table, a drawing table, and a dining table. This is achieved by the use of various mechanical linkages such as spring return, sliding joints, hinges, and other mechanisms (Khan J et al., 2014). Same goes to this multipurpose step stool which it serves variety of functions which are a step stool, bench to sit, trolley and storage purpose by the use of sliding mechanism on the legs part for adjustability function. A step stool with a handrail facilitates safe positioning. It becomes more stable when the footprint of an object is increased without modifying other physical variables (e.g., height, weight and etc.) (Michael Wiklund et al., 2019).

There are several different types of step stools, each with its own style, function, and material. Step stool also comes in folding type appearance. One such prior art step stool is described in a published patent application US20160017658A1 entitled “Step Stool and Method” (Thomas W. Parker, 2016) in the US patent. The step stool includes a rear rail assembly, pivotally connected to the front rail assembly, having a crossbar. A published patent application USD632101S1 “Step Stool with Handles” in the US patent is an example of prior art step stool. This invention relates to a step stool with a base and handles to make it easier to move and travel (Tohoda et al., 2012). Step stools come in a number of shapes and sizes, and they can be used for a variety of purposes. One invention is for an apparatus that offers a stable step stool to help a person climb into an elevated vehicle (Box et al., 2000). The step stool can be adjusted in height and has foot pads that can be used to apply a stabilizing weight.

Objectives of this research are to design a multipurpose step stool that can serve functions as a step stool, sitting bench, trolley and storage purpose. This research will focus on innovation of existing product and it will be design by using Inventor 2019 software. Then, the result will be analyzed by using Finite Element Analysis software (FEA). Users can validate component designs using Autodesk Inventor's finite element analysis feature, which allowed to evaluated part performance under load. Users can design parameters within assembly stress areas and compare design options with the help of optimization technology. After that, the optimized parameters are used to update the 3D model (Andreas Welling, 2019).

2.0 METHODOLOGY

The chosen material which is mild steel, will be compared to aluminum to study the differences in terms of Von Mises Stress, displacement and safety factor. The reliability of the step stool's frame structure will be analyzed and subjected to 150 kg loads. This project consists of three main stages, which are as follows:

- Conceptual Design.
- Strength analysis on the frame structure using CAD software.
- Fabrication process and testing.

2.1 DESIGN AND DEVELOPMENT

2.1.1 Design Concept

Various types of step stools available in market will be identified according on patent applications were studied to determine the primary design attributes. The aim is to find the best step stool design that can replace the existing wooden pallet used by student and providing multipurpose functionality. Through this phase, three design concepts were proposed as shown in Figure 1.

(a) Design Concept 1 (b) Design Concept 2 (c) Design Concept 3

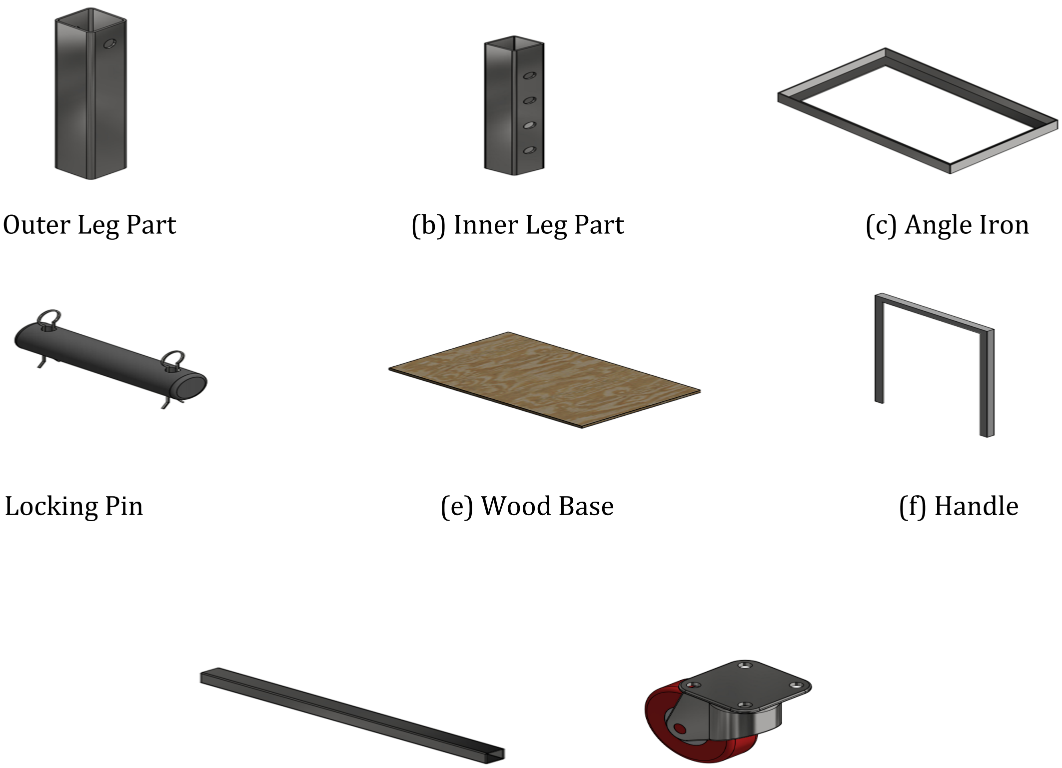
Figure 1: Design Concept of step stools

There are three suggested design which is illustrated in Figure 1. The concept of design for (a) design concept 1 has two different height of step and has an added function which is the mini vice at the side of the step platform. Its disadvantages are small platform of step and look unstable. The second design concept is enhanced from the first step of the step stand which can be lifted- up on the back of the product and give function as a back-up for user to lay the back body when sitting. It helps in reduces spaces for storing it. The mini vice still be used as a second function and the addition of a dolly at the back leg for easily move.

Design Concept 3, depicted in Figure 1 (c), is the final design selected, which has been tweaked to improve its functionality. The previous design concept is linked to mini vice machinery, while the last design concept does not. The location of the mini vice was not suitable because the level height of the step stool is too low to accommodate this feature. The final design includes a mechanism that allows the step stool's top to be adjusted and locked at various heights. For added stability, the step stool has a wider base for stepping. Furthermore, the outer legs could be relocated and replaced with another leg that has been assembled or welded with a dolly to provide a trolley feature.

2.1.2 Final Concept Selection (Parts)

The final concept of parts using in fabricating the steps stools are shown in Figure 2. Some of the parts are available in the market and need to undergo various types of operations such sawing, drilling, welding and joining. All these parts are producing according to the drawing except for locking pin and tire are the standard parts which are purchased as shown in Figure 2(d) and (h) respectively.



(a) Outer Leg Part (b) Inner Leg Part (c) Angle Iron

(d) Locking Pin (e) Wood Base (f) Handle

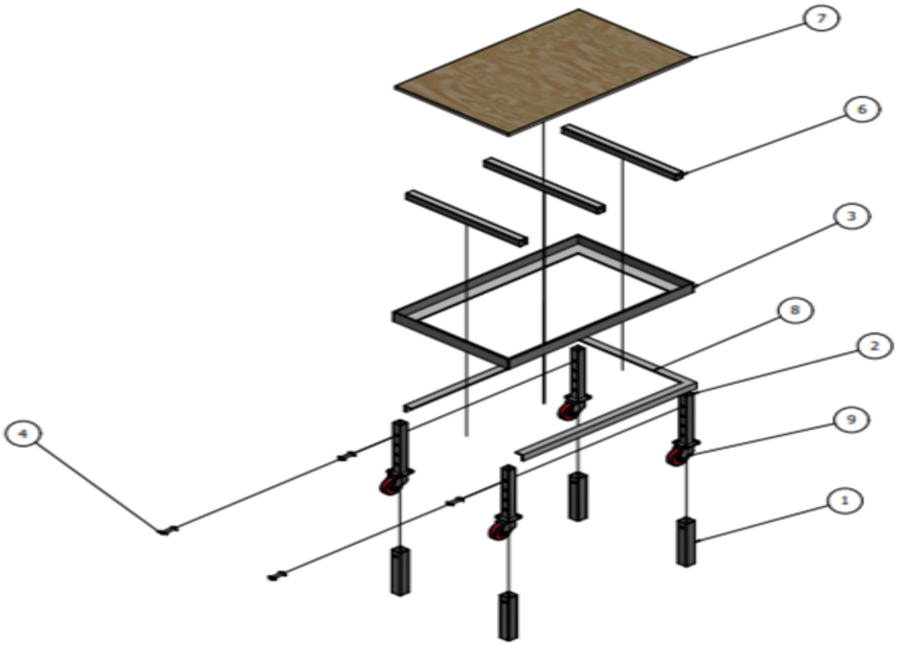
(g) Steel Support (h) Tire

Figure 2: Parts for multipurpose step stool

2.2 FINAL DESIGN

2.2.1 Exploded View

As shown in Figure 3, this exploded view shows all the parts represent the final design. It includes an adjustment shape on legs part which allowing the top of the step stool to be placed and locked at variable heights. Locking pin will be used to lock the legs at level of height required. The step stool has a wider base for better stability. Moreover, the outer legs can be moved and replaced with another leg that has been assemble or weld with dolly which can give a function as trolley. It also helps user to move around the product easily.



1. Inner leg part
2. Outer leg part
3. Angle iron
4. Locking pin
5. Steel support
6. Wood base
7. Handle
8. Tire

Figure 3: Exploded View

3.0 RESULTS AND DISCUSSION

3.1 FINITE ELEMENT ANALYSIS (FEA)

The frame structure of the step stool will be analyzed using finite element analysis since it is the most important and critical component. It will be subjected to 150 kg loads to see whether it can withstand them and to determine where the design's flaws are. The results of a finite element analysis on a mild steel frame construction will be compared to the results of a finite element analysis on a different material, aluminum. Von Misses stress, displacement and safety factor results were derived from this study. The result of a finite element analysis performed with Autodesk Inventor software is shown below.

3.1.1 Material: Mild Steel

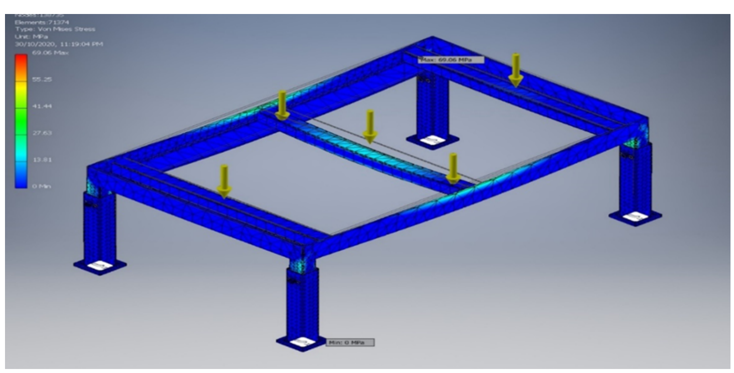


Figure 4: Von Mises Stress for Mild Steel material

It is worth indicated that the overall stress at the frame structure was 69.06 MPa, which is significantly less than the material's maximum Yield Strength of 207 MPa as shown in Figure 4.

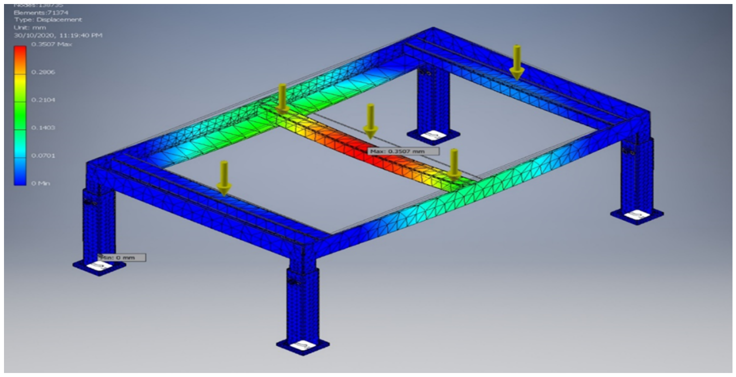


Figure 5: Displacement for Mild Steel material

Figure 5 shows the overall movement of the X, Y, and Z axes, the mean displacement is 0.3507 mm. This displacement occurs due to a force of 1500N exerted by all surface of the frame structure.

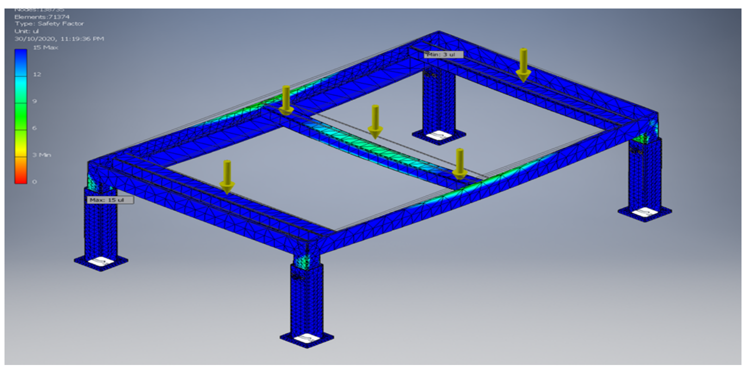


Figure 6: Safety Factor for Mild Steel material

The result reveals that the safety factor's minimum value is 3. If value of safety factor is 1.0 or lower, component is likely to fail. Areas reaching a minimum safety factor of 0 are shown in red by default, indicating where the component is most likely to fail. The blue color on the above diagram indicates that this structure in a good condition as shown in Figure 6.

3.1.2 Material: Aluminum

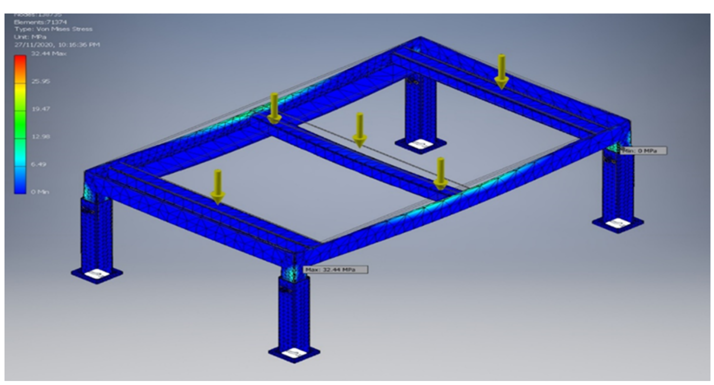


Figure 7: Von Mises Stress for Aluminum material

The overall stress at the frame structure was 32.45 MPa, which is slightly less than the maximum Yield Strength of the material, which is 55 MPa as shown in Figure 7.

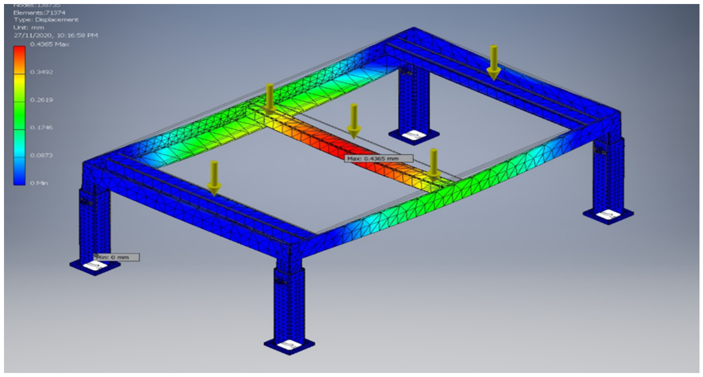


Figure 8: Displacement for Mild Steel material

Figure 8 shows the maximum displacement shows the value of 0.4365 mm in the overall movement of X, Y and Z axis. This displacement occurs with a force exerted onto the frame structure of 1500N.

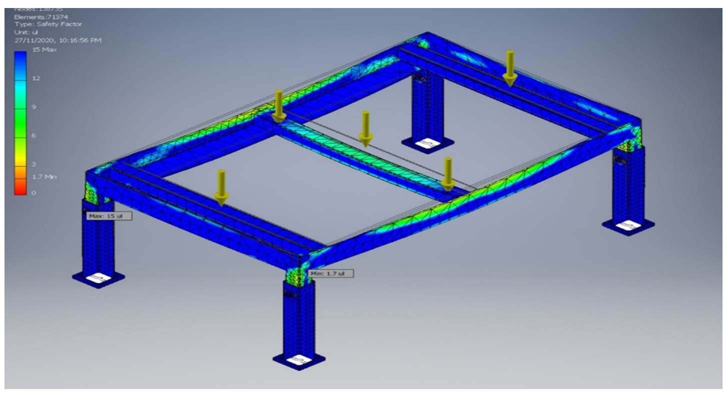


Figure 9: Safety Factor for Aluminum material

The result reveals that the safety factor's minimum value is 1.7. If safety factor is 1.0 or lower, component is likely to fail. Areas reaching a minimum safety factor of 0 are shown in red by default, indicating where the component is most likely to fail. The blue color on the above diagram indicates that this frame structure is safe as shown in Figure 9.

3.2 SUMMARY OF ANALYSIS

Based on the results as shown in Table 1, mild steel and aluminum were compared in terms of Von Mises Stress, displacement, and safety factor. This study was carried out to determine if the frame structure of a step stool is capable of supporting a weight of 150 kg. The analysis has been completed by using Autodesk Inventor stress analysis feature. The results indicated that mild steel is the best and better material to be used in term of cost manufacturing process comparing with aluminum which is quite expensive and required special welding techniques.

Table 1: Results comparison between mild steel and aluminum

MATERIAL	MAXIMUM YIELD (MPa)	MATERIAL YIELD (MPa)	DISPLACEMENT (mm)	SAFETY FACTOR (Min)
MILD STEEL	69.06	207	0.3507	3.0
ALUMINUM	32.45	55	0.4365	1.7

The Von Mises Stress is a metric for determining whether a substance can yield or fracture. When an isotropic and ductile metal is subjected to a complex loading state, the Von Mises Stress is often used to determine if it will yield. The Von Mises Yield Criterion is calculated by comparing the Von Mises Stress to the yield stress of the material. For Von Mises Stress, the values predicted by software are acceptable because those values did not exceed from yield strength of 207 MPa for mild steel and 55 MPa for aluminum. If the amount of stress does not exceed the yield point, the material will revert to its original shape, but if it does, it will deform.

For displacement, mild steel material has the smallest displacement value of 0.3507 mm, while aluminum has the largest displacement value of 0.4365 mm which ensures mild steel bends just slightly from its static position. The force of 150 kg on mild steel material only causes a little displacement than aluminum which indicates the magnitude of deformation from the original shape. When loads and supports are added, the displacement result value indicates how often the model displaces or deflects. The model's red areas have the most displacement.

Value of safety factor show that the value for aluminum material is lower than mild steel which is 1.7 while for mild steel, higher than aluminum and exceed 1.0 which is 3.0. It means the material used is relevance and safe to be used. The safety factor's result value indicates which sections of a model are at risk of yielding under stress. When deciding the overall factor of protection for the frame design, the safety factor for each part's material is taken into account. If the factor of protection is less than 1.0, the design or component is at risk of failure. Areas reaching a minimum safety factor of 1.0 are highlighted in red by default, indicating the most likely failure location. Aspect of safety analysis accuracy is dependent on providing precise loads, materials, and models as data. There is no one-size-fits-all protection factor. Then, mild steel is better material to use since its safety factor is higher than aluminum.

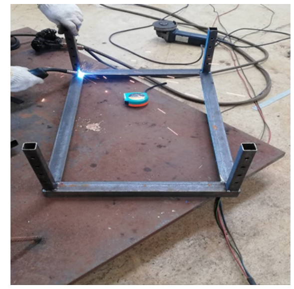
3.3 FABRICATION PROCESS

After concept design and analysis of multipurpose step stool frame was finalized and done, the fabrication process is start based on proposed design. All of the fabrication and assembly process were shown in upcoming Figure 10 (a) – (e). The main process involved was cutting, welding and drilling process. The assembly are including all parts of the product such as angle iron for frame, inner leg part, outer leg part, handle, dolly and locking pin. All the parts were connected and assembled by welding operation.

The final product assembly, shown in Figure 10(d), is a step stool without a dolly that serves as a step platform for getting to the milling machine's setting position. The legs can be raised or lowered by up to 4 cm on each step. As shown in Figure 10(e), the final product assembly with dolly performs as a trolley. The product's handle was also added to it, and it can be stored separately for act as trolley purposes to transport the stuff.


(a) Cutting


(b) Drilling


(c) Welding


(d) Final Product Assembly (Without Dolly)


(e) Final Product Assembly (With Dolly)

Figure 10: Fabrication process for step stool

4.0 CONCLUSIONS

It could be concluded that the current pallet used by UC TATI students can be replaced by this step stool, which has a multipurpose feature and simple to use.

a) This product serves a variety of purposes for the customer, including a step stool, a bench to sit on, a trolley, and for storage purpose. It overcomes the limitations of the current pallet, which are wide, heavy, and have an inappropriate design. The first goal, which was to design a multipurpose workshop step stool, was completed successfully. The 2D design was produced included all of the product's requirements and, as a result, it made the next step easier.

b) The frame of this product was analyzed using Software Inventor 2019 and the results revealed that the frame can withstand a maximum load of 150 kg, with a displacement value of 0.3507 mm for mild steel which is less than aluminum and a safety factor of 3.0 for mild steel which are higher than aluminum. This means that the material (mild steel) is superior comparing with aluminum in terms of performance, relevance, and safety.

c) The fabrication was accomplished successfully because the parts were well-assembled according to the drawing and functioned as intended and tested. The process of cutting, drilling, and welding were the key operations and processes to fabricate the multipurpose step stool. The finite element analysis was conducted to analyze the performance of the product and served as intended to overcome the issues raised in the UC TATI's workshop.

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