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Design A Portable Lifting Machine for Transfer Heavy Bricks in Construction Sites

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Abstract

The booming Malaysian residential construction industry demands faster and safer methods. Manual bricklaying risks worker safety due to physical strain. This project proposes a portable lifting equipment to expedite bricklaying and enhance safety. It begins with hazard analysis, emphasizing musculoskeletal risks and severe injuries. The goal is a user-friendly machine lifting bricks within 3.5 until 5 meters, carrying 80.51 kg, transferring 2368 bricks hourly. SolidWorks aids in 3D modeling, motion analysis, and precision engineering drawings. The final design boasts anti-corrosion, durability, standardized components, and George E. Dieter's principles integration. It's poised to outperform manual lifting, promising cost-effectiveness and practicality. This innovation can transform bricklaying, enhancing efficiency, safety, and construction performance significantly in Malaysia.

1. Introduction

The construction sector in Malaysia is a crucial economic contributor, constituting around 4% of the GDP in 2020. [1] Forecasts predict a steady rise, with the construction market projected to grow over 2% annually from 2021 to 2026. [1] Within this, the residential construction segment, driven by urbanization, is set to expand by 18.7% in 2022 and maintain an average growth of 7.1% yearly till 2026, particularly in cities like Kuala Lumpur, Penang, and Johor Bahru. [2] Despite this growth, manual bricklaying, fundamental to construction, poses significant health risks. The process involves lifting heavy bricks and mortar, leading to musculoskeletal disorders (MSDs) like back pain and hand-arm vibration syndrome (HAVS), impacting workers' well-being [4].

This project aims to design a compact, user-friendly portable lifting machine to ease physical strain in bricklaying across Malaysian construction sites. The machine targets a height range of 3.5 to 5 meters, utilizing SolidWorks for precise modeling, simulations, and engineering drawings, ensuring durability and standardized components. This innovation could transform bricklaying efficiency and safety in the construction industry, especially in house construction. The portable lifting machine promises quicker and less strenuous brick transportation, enhancing productivity and worker safety. Its adaptability across various industries requiring heavy lifting signifies its potential cost-effectiveness and versatility as a solution in industrial settings.

2. Literature Review

A literature review is a critical analysis of existing research on a topic. It aims to provide a comprehensive and helps increase knowledge by giving a thorough understanding of existing research, finding gaps in knowledge, and combining various viewpoints to expand one's understanding. It is carried out by collecting data through patent, analysis, books, journals, and current product that would be comparable and used for product design. Manual lifting and transferring heavy bricks involve workers manually carrying bricks on their backs and heads, [5,6] along with passing bricks by throwing them upward to another level. [7] This manual process increases physical strain and the risk of injuries like strains and muscle tears, exacerbated by the lack of tools or machinery. Moreover, this approach is time-consuming and inefficient since workers can only carry a limited number of bricks simultaneously, necessitating frequent trips. This method also escalates the risk of accidents and potential damage to the structure of the bricks.

Besides, the alternatives method for transferring heavy bricks to higher levels in house construction typically involves the use of scaffolding and hoisting equipment like crane lifting machine and material lifting machine, conveyor systems or conveyor belts and robotic brick-laying machine. In addition, the presence of a product in the market affects both demand and cost factors. In the market, there are various types of lifting machines used for moving heavy materials and bricks at construction sites, each with its own level of capability and performance. By analysing market data, designers can effortlessly gather ideas and information from existing products, which can aid in the development of a new design that offers improved performance. Table 1 shows the available product in the market.

Table 1 *Available Product in the Market*

Specification	EH-500UT Electric Material Hoist	Technique 7M Brick / Block Elevator	Bumpa Hoist	Construction Material Elevator
Figure				
Manufacturer	Safety Hoist Company	Technique Tools	Mace Industries Ltd	Shandong Deou Heavy Industry Machinery Co., Ltd
Machine Type	Platform material hoist	Brick elevator	Conveyor	Lift Chain
Max. Payload (kg)	226.8	150	80	500
Lifting speed (m/min)	Not specified	Not specified	20	26
Dimension	H: 8.5 m – 13.4 m W: 0.6 m – 1.0 m	7 m (unfolded), 3 m (folded)	806cm*62cm*83cm (for 8 m) 1006cm*62cm*83cm (for 10 m)	8 m – 120 m
Weight (kg)	136	110.6	110.6 (for 8 m) 119.6 (for 10 m)	Not specified
Price (RM)	19,703.91	36,916	23,633.54 (for 8 m) 25853.53 (for 10 m)	4,748.32

3. Methodology

This process, consisting of steps like conceptual design, embodiment design, and detail design, enables engineers to efficiently find solutions to problems. Various design process methods, such as those proposed by Pahl and Beitz, George E. Dieter, and Rudolph J. Eggert have been suggested. However, in this project, the engineering design process by George E. Dieter is being utilized. Based on the design process introduced by George E. Dieter, it mainly consists of three phases of design which are conceptual, embodiment, and detail. Conceptual design, phase one included four stage which are define problem, gather information, concept generation and evaluation of concepts. While for embodiment design, phase two consist of three stage which are product architecture, configuration and parametric. Lastly, detail design, phase three consists of one stage. Figure 1 shows the flow chart of the design process introduced by George E. Dieter.

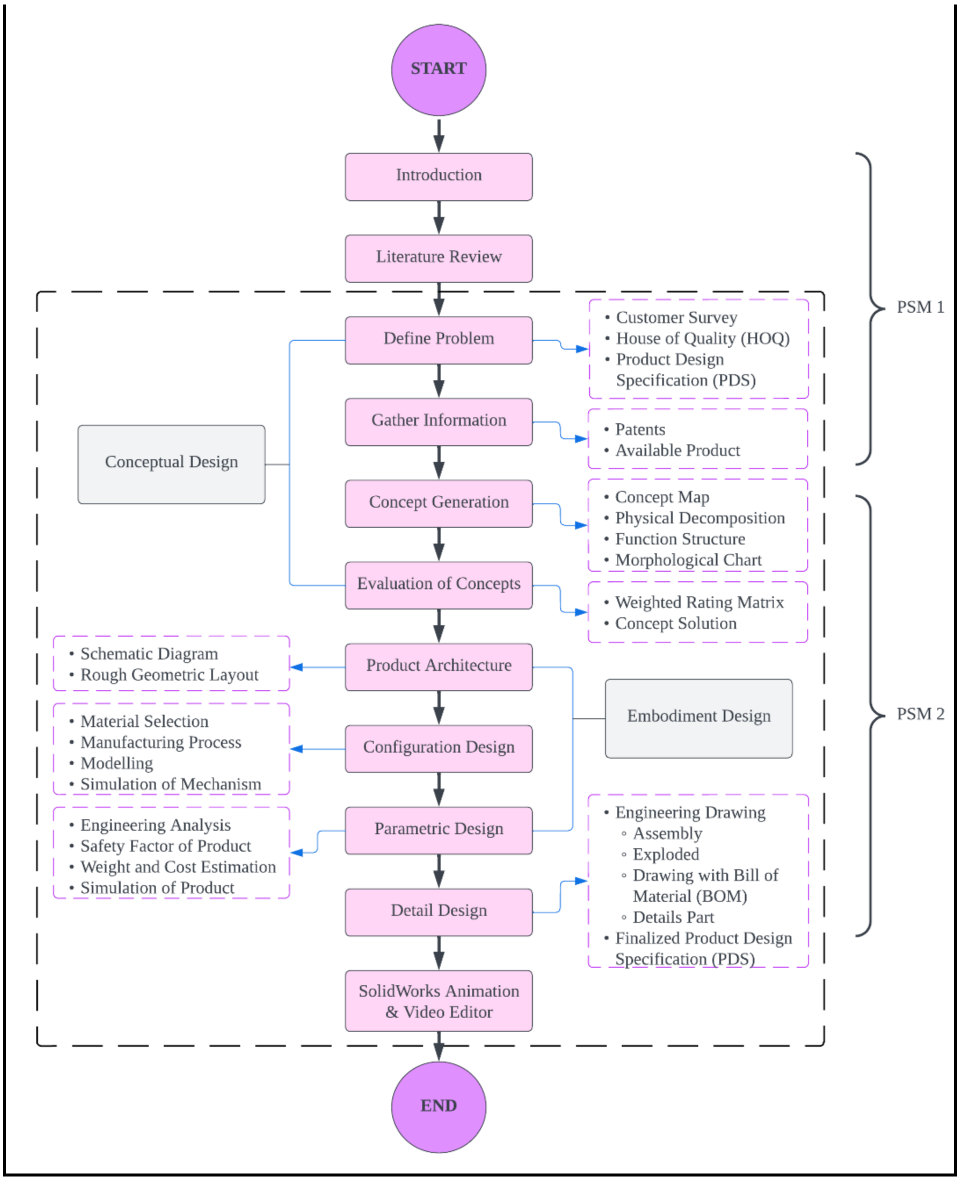

Fig. 1 *Flowchart of design process*

4. Design Process

The design process aims to guide students through a logical sequence of activities to solve a real-life problem with an effective design solution. In order to determine and study the customer's need for a lifting machine for heavy bricks, a Google Forms online survey was conducted. The survey's title is "Survey of the Product Design Specification for Bricks Lifting Machine in House Construction Sites". The objective tree is used to examine the respondents' results, and the relative weighting is utilised to identify the Product Design Specifications (PDS).

The objective tree provides a simple and obvious way to illustrate the requirements for the product that should be carried out during the design phase. By agreeing on the finalised objective tree before moving on to the design, it helps to reduce any misunderstanding between customers and the designer. A brick-lifting machine's objective tree diagram is presented in Figure 2 and Table 2 shows product design specification.

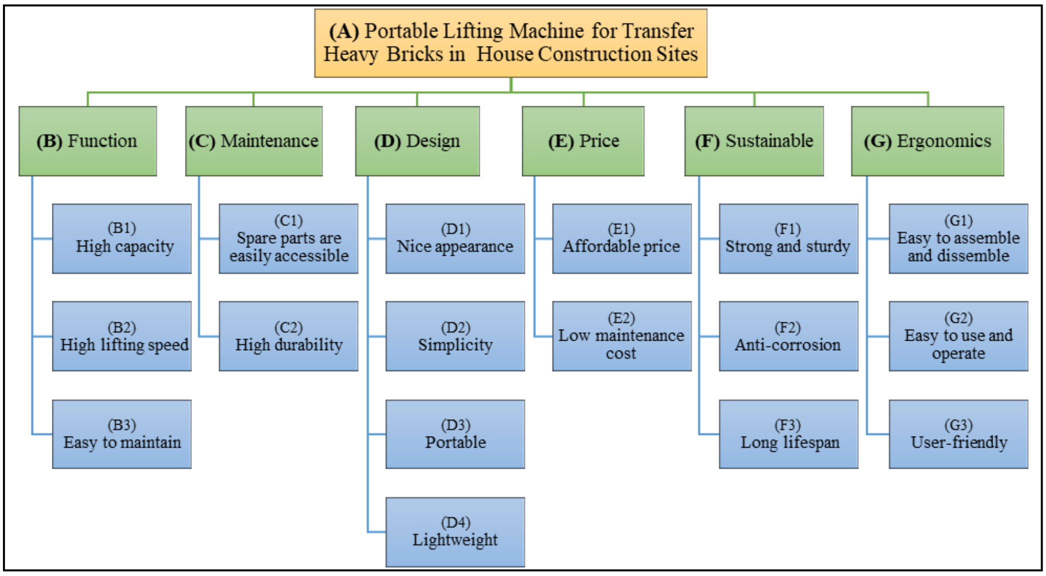

Fig. 2 *Objective Tree of Brick Lifting Machine*

Table 2 *Product Design Specification*

Introduction	
Title	A Portable Lifting Machine for Transfer Heavy Bricks in Construction Sites
Design Problem	To transferring heavy bricks to a higher level mainly in house construction sites.
Intended Purpose	To enhance the efficiency and safety of transferring heavy bricks during bricklaying process
Target Customer	Construction companies, masons and bricklayers, renovation and repair contractors, equipment rental companies, government agencies and public works departments, building material suppliers
Customer Requirement	
Functional Performance	• The machine should have a maximum payload of 150 kg. • The lifting speed for this machine should be more than 25 meters per minute • Easy to maintain the machine • The height of the product is 5 meters.
Design	• The design should be straightforward and appealing, with an even finish that reflects current market trends. • Portable • Lightweight • The weight should be below than 100 kg.
Price	• The selling price of the machine should be less than RM 10,000 • Low in maintenance cost
Sustainable	• Strong and sturdy • Anti-corrosion • Longer lifespan with more than 10 years
Operating Environment	• Suitable for any types of roads or surface that are usually bumpy and uneven
Geometric Limitation	• The machine should be portable • Easy to move and store
Maintenance, Repair, Retirement	• The machine should have low maintenance and repair needed during the economic life. • Spare parts are easily accessible
Reliability, Robustness	• No failure occurs during the economic life • All parts should have high resistance of corrosion • The machine should withstand 6 hours per day for operating.
Safety	• The machine is stable and without any major failure occurs within its economic life.
Ergonomics	• Easy to assemble and dissemble • Easy to use and operate the machine

4.1 Concept Generation

Methods including morphological charts, physical and function decomposition, and brainstorming were discussed during this stage, where the aim is to generate concepts for products that can fulfil the functions that the product needs. The Portable Brick Lifting Device's functional construction is depicted in Figure 3.

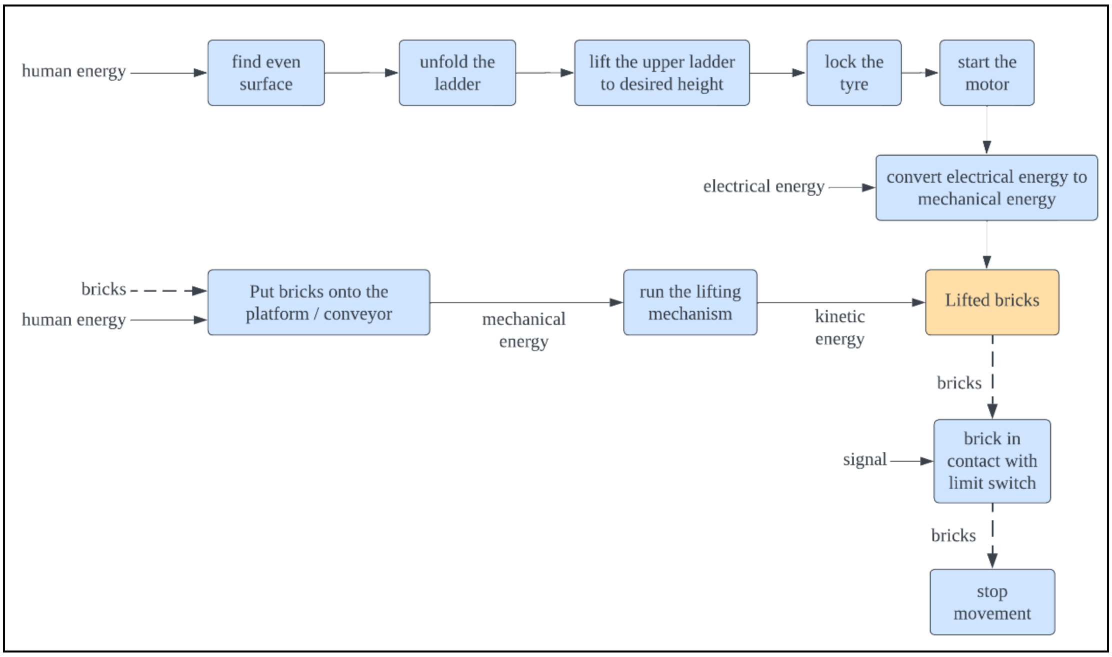

Fig. 3 *Function Structure*

By combining a weighting factor derived from the objective tree survey with the design requirements, a weighted decision matrix was utilised to assess and analyse the range of concepts among the three alternatives based on the morphological chart. This approach makes it possible to identify the best concepts that satisfy the requirements of customers. Following evaluation, the concept combination that receives the highest rating will be chosen to move on to the next phase. The device's concept combination is displayed in Table 3.

Table 3 *Product Design Specification*

No	Function	Selection Concept
1	Power Source	Electric generator
2	Lifting Mechanism	Conveyor
3	Frame Design	Ladder frame structure
4	Mobility and Base	Heavy duty wheeled base with swivel casters
5	Stopping Mechanism	Mechanical limit switch

4.2 Product Architecture

Product architecture is a vital step in product development, as it defines the physical structure and components of the product that perform its intended function. Product architecture is derived from the function structure, which is a part of the concept generation process. The purpose of product architecture is to group the functional elements into clusters that will form the modules of the product. A schematic diagram as shown in Figure 4 is used to show the arrangement and interaction of the physical elements in the product architecture.

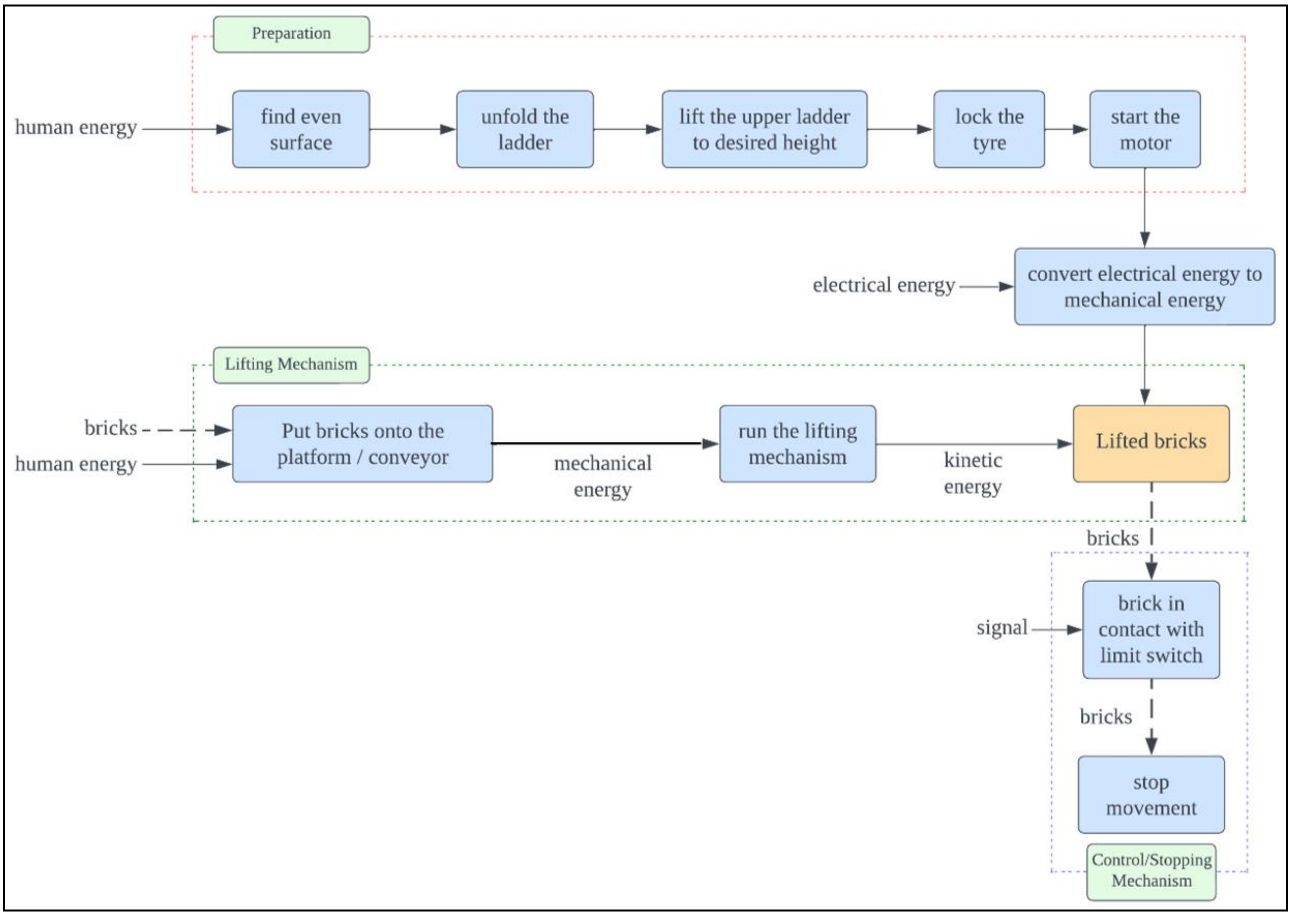

Fig. 4 *Schematic Diagram with Clustered Elements*

4.3 Modelling

The 3D models of this machine were created using SolidWorks software, a computer-aided design tool. The models were based on the concepts that were chosen in the previous stage of the project. These components were then integrated to form the final product which is a Portable Bricks Lifting Device. Figure 5 shows the full assembly of the device.

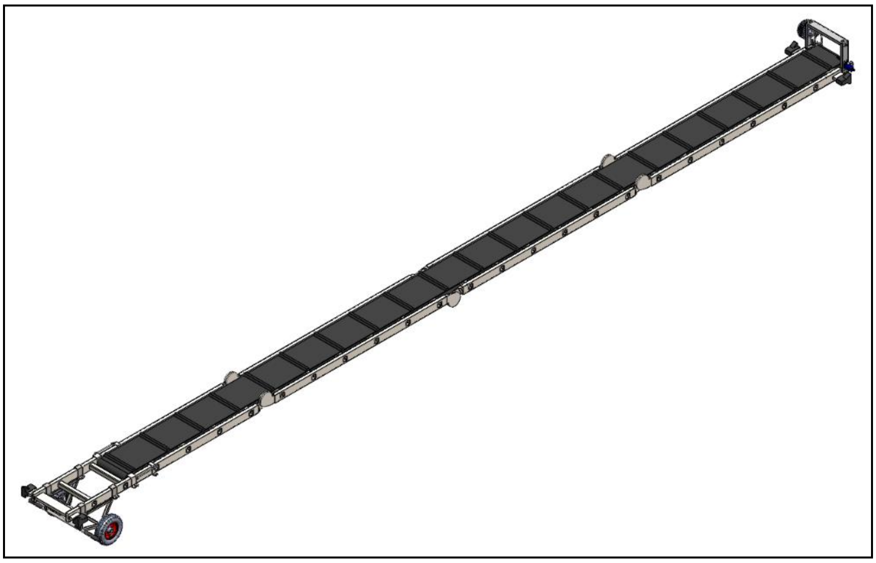

Fig. 5 Full Assembly of Portable Bricks Lifting Device

4.4 Power Source

The upper assembly, positioned at the top end of the conveyor belt system, likely houses mechanisms, including a motor and gear system, to drive belt movement. The motor powers sprockets at both ends, initiating movement by rotating a connected chain, transferring motion to the conveyor belt roller. The rotating rollers create friction, propelling the belt along its path. Figure 6 illustrates the motor-operated rotation of the chain and roller.

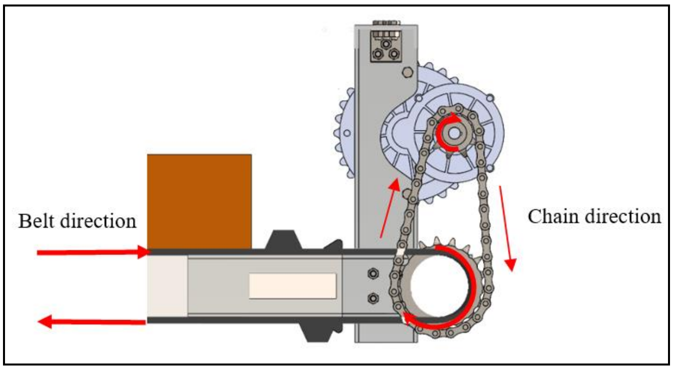

Fig. 6 Power transmission system of the Portable Bricks Lifting Device

4.5 Lifting Mechanism

Lifting mechanism in this system employs a conveyor belt mechanism designed specifically to lift materials, such as bricks, from a lower level to a higher level. Utilizing the force of gravity and the frictional grip of the belt, bricks are placed on the inclined section are moved upwards due to the belt's incline. Figure 7 below shows the movement and motion of the device to elevate the bricks.

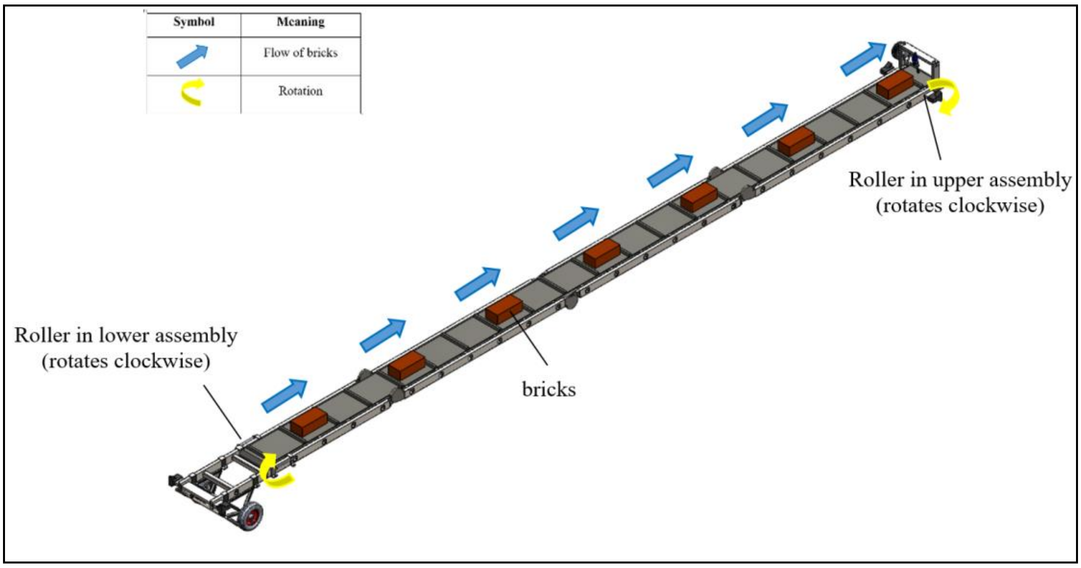

Fig. 7 The working process of the Portable Bricks Lifting Device

4.6 Transfer Rate Analysis

This evaluation aims to check if all these components can lift the bricks efficiently. The diagram in Figure 8 shows how a motor transfers motion and force to a roller using sprockets and a chain.

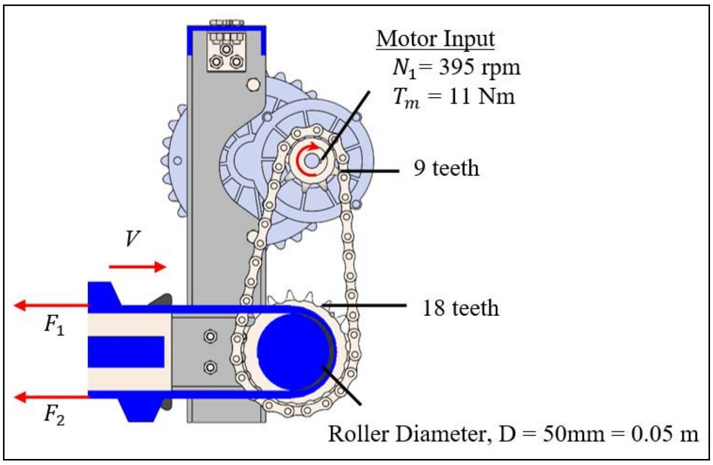

Fig. 8 Cross sectional view of the device with α = 0°

Calculate the speed of roller, N_2 by using formula:

$$\text{Roller speed, } N_2 = \text{motor speed} \times \text{sprocket ratio} = 395 \times \frac{9}{18} = 197.5 \text{ rpm}$$

Then, calculate the speed of belt, V by using formula $V = \omega r$

$$\text{Belt speed, } V = \omega r = \frac{2\pi N}{60} \times \frac{D}{2} = \frac{197.5\pi}{60} \times 0.05 = 0.517 \text{ m/s}$$

Convert 0.517 m/s to m/min by using formula:

$$\frac{0.517\text{m}}{\text{s}} \times \frac{60 \text{ s}}{\text{min}} = 31.02 \text{ m/min}$$

Next, calculate the torque at the roller by using formula:

$$\text{Torque at roller, } T_R = \frac{0.517\text{m}}{\text{s}} \times \frac{60 \text{ s}}{\text{min}} = 31.02 \text{ m/min}$$

By assuming

- compression force, $F_2 = 0$ (slack side)
- tensional force, F_1 = Effective pull, F_U

Then, find the value F_1 by using the formula:

$$Fr = T_R$$
$$(F_1 - F_2)r = T_R$$
$$F_1 = \frac{T_R}{r}$$
$$F_1 = \frac{22}{0.025}$$
$$\frac{22\text{Nm}}{0.025} = 880\text{N}$$

Hence, the maximum force that the device can handle is 880N.

Calculate maximum payload in kilogram (kg) by considering the machine angle of inclination, $\alpha = 45°$ as shown in Figure 9.

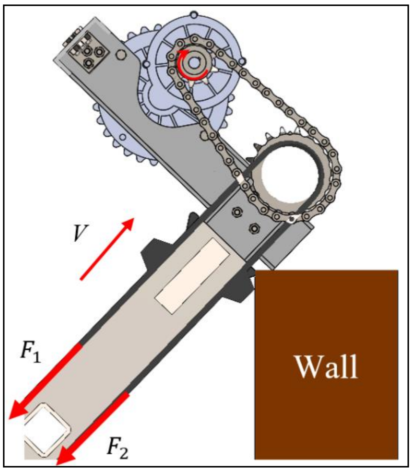

Fig. 9 Cross sectional view of the device with α =45°

The effective pull, F_U formula:

$$F_U = \mu_R \cdot g\,(m + m_B + m_R) + g \cdot m \cdot \sin\alpha \quad [N]$$

Where,

F_U	=	Effective pull
μ_R	=	Friction coefficient when running over roller = 0.35
g	=	Acceleration due to gravity = 9.81 m/s^2
m	=	Mass of the goods conveyed over the entire length conveyed (total load)
m_B	=	Mass of the belt = 12.5 kg
m_R	=	Mass of roller = 0.62 kg
α	=	Machine's angle of inclination = 45°

$$880 = 0.35 \times 9.81(13.12 + m) + 9.81 \times m \times sin45°$$
$$880 = 3.4335\ (13.12 + m) + 6.937m$$
$$880 = 45.048 + 3.4335m + 6.937m$$
$$10.3705m = 834.952$$
$$m = 80.51\text{kg}$$

Hence, the maximum payload of this device is 80.51kg.

The mass of one brick is 2.5kg.

$80.51\ \text{kg} \div 2.5\ \text{kg} = 32.2\ \cong 32$ bricks
Therefore, the maximum bricks that the device can handle at a time is 32.

Next, find the total load handle in one hour.

1 hour = 3600 seconds

$$\text{Distance covered in one hour} = \text{Velocity} \times \text{Time}$$
$$= 0.517m/s \times 3600s = 1861.2\ m$$

$$\text{Total load handle in one hour} = \frac{\text{Total distance covered}}{\text{Distance covered in one cycle}} = \frac{1861.2m}{12.5m} = \cong 148.9 \text{ cycles (full cycle)}$$

However, only half the cycle is necessary because we load the bricks solely at the top. So,

$$148.9 \text{ cycles} \div 2 = 74.5 \text{ cycles} \cong 74 \text{ cycles.}$$

Therefore, with a total distance covered in one operation of 12.5 meters and a velocity of 0.517 m/s, the device can handle the load approximately 74 times in one hour.

$$74 \text{ cycles} \times 32 \text{ bricks} = 2368 \text{ bricks}$$
$$2368 \text{ bricks} \times 2.5\text{kg} = 5920\text{kg}$$

The number of bricks that the device can transfer in one hour is 2368.

4.7 Simulation Analysis

Two analyses have been conducted on the Portable Bricks Lifting Device, specifically focusing on the wheel frame: Von Mises stress analysis and factor of safety assessment. The maximum stress recorded is 32.82 MPa, as illustrated in Figure 10. Conversely, the minimum factor of safety for this machine is 6.7, surpassing the recommended threshold of 1. Therefore, the machine is deemed safe, as depicted in Figure 11.

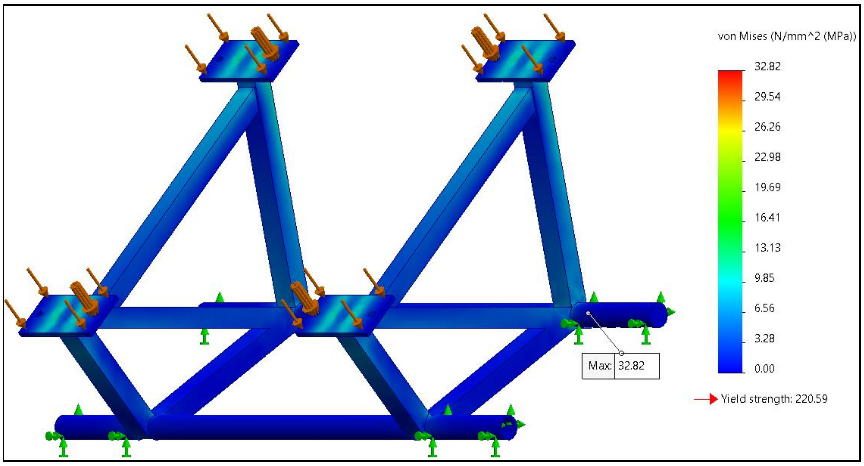

Fig. 10 Von Mises Stress analysis of wheel frame

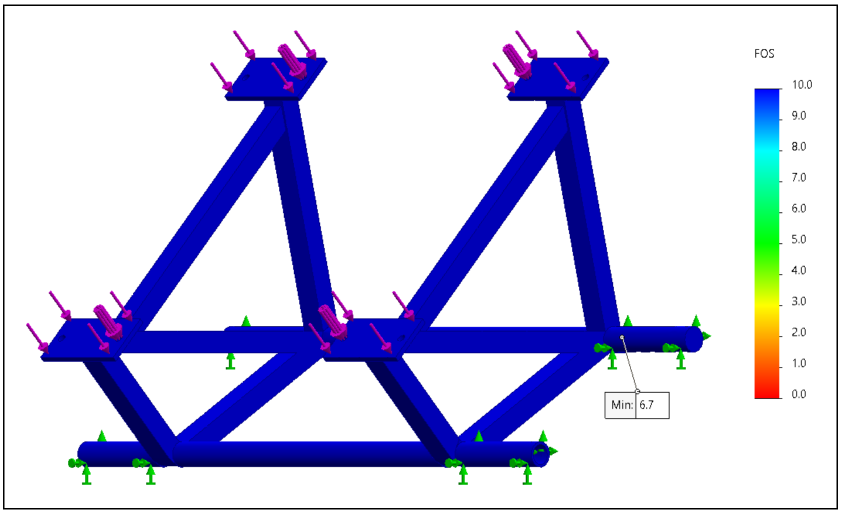

Fig. 11 Cross sectional view of the device with α =45°

4.8 Product Specification

Product specifications work as a guidance, defining all the specific requirements and details that must be fulfilled by a product in order to direct its development and guarantee that it satisfies quality standards and consumer needs. Table 4 below shows the product specification of Portable Bricks Lifting Device.

Table 4 *Product specification of the machine*

Detail	Product Specifications
Max. Payload	80.51 kg
Capacity (per hour)	2368 bricks (5920 kg)
Dimension	6755 mm (L) × 320 mm (W)
Maximum Height (m)	5
Lifting Speed (per min)	31.02
Weight (kg)	43.14
Power (W)	450
Price	RM3789.54

5. Conclusion

Conclusively, the design approach for the Portable Lifting Device for the Transfer of Heavy Bricks in Construction Sites aligns with the concepts proposed by George E. Dieter. The main goal of this project is to create a compact and simple device that can lift and move heavy bricks to any desired height and position within a construction site. The intention is to improve the efficiency and speed of bricklaying. The device eliminates the need for the physical lifting of heavy bricks, which reduces the amount of time required for the lifting and transferring process. The primary purpose of this device is to elevate and transport large bricks with accuracy, enhancing the operation's overall efficiency. By using SolidWorks software, the device's components have been carefully devised, simulated, and evaluated, resulting in detailed engineering drawings.

The device's final design is made to work with 80.51 kg of maximum payload and lift at a speed of 31.02 meters per minute, which is more than 25 meters per minute requested by the customer. For one hour of operation, this device can transfer a total of 2368 bricks. The selection of materials, which includes anti-corrosion features, high strength, high durability, and standard parts, guarantees longevity and reliability even in challenging construction site environments. This portable lifting device is expected to exhibit much higher efficiency than manual lifting techniques, offering a practical and valuable option for construction industries. As the construction industry evolves, this innovative solution is well-positioned to increase productivity and operational efficiency, marking a noteworthy advancement in construction technology.

Acknowledgement

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