

BAMBOO SPLITTER MACHINE DESIGN USING QFD APPROACH

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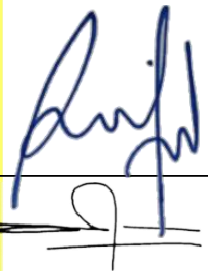
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DEDICATION PAGE

This undergraduate thesis that drains a lot of time, resources, and energy is dedicated to my family. For my mother Ririen Noviyanti S.T., my sister Verisya Rahmania Permana, my brother Vabian Atala Ramadhan Permana, and my father Alm. Sani Dian Permana S.T. that always support me in any situation although it took me ages to finish it. also, my friend in Fakultas Teknik Industri UII that helps me during my study in UII.

MOTTO

“Chance doesn’t come twice, so take it and do as best as you can” -Myself.

PREFACE

Assalamu 'alaikum Wr. Wb.

Al-hamdu lillahi rabbil 'alamin and gratitude are presented to Allah SWT for all blessing, opportunity, health, love, and mercy, who granted the author willingness and inspiration to complete and finish undergraduate thesis to acquire the degree of Sarjana Teknik, which entitled “BAMBOO SPLITTER MACHINE DEVELOPMENT USING QFD APPROACH” And greeting devoted to our beloved Prophet Muhammad SAW who has brought humankind to a world with full of knowledge thru today.

This report is dedicated to the family of the author and all of the readers, specifically Industrial Engineering Department students as one of the collections to developing knowledge, therefore author would thank those who gave their support and motivation to the author to finish this internship report:

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Wassalamu`alaikum warahmatullahi wabarakatuh

Yogyakarta, March 2023

A handwritten signature in black ink, appearing to read 'Verrel' followed by a stylized flourish.

Verrel Imansyah Permana

ABSTRACT

Indonesia become one of the highest bamboo product exporters in the world. Indonesia is recorded as being ranked third in the world. To maintain it, industries need a reliable machine, unfortunately. The current machine is having several issues regarding the durability aspect of the bamboo splitter machine that is commonly used in the industries that work with bamboo. This is quite a problem because several the components of that machine is frequently replaced due to the design factor and the high impact when splitting the bamboo. Based on that problem, the researcher found out that Quality Function Deployment is the suitable method to solve the problem, mainly Quality Function Deployment is heavily based on customer needs/requirements. QFD method is a method to develop a product based on the voice of customer of the product. According to Yoji Akao (1990) the founder of QFD, QFD is a methodology to translate the needs of the customer to design a product that is based on what the customers want and need. The result found out 8 attributes that important for customers, which is “Process Time”, “Safety”, “Durability”, “Precision”, “Easy to use”, “Customization”, “Affordability”, and “Portability”. And the improved design is created based on the analysis using the QFD method.

Keywords: Quality Function Deployment, QFD, House of Quality, HOQ, Bamboo Splitter Machine

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CHAPTER 1

INTRODUCTION

1.1 Background

Indonesia become one of the highest bamboo product exporters in the world. Indonesia is recorded as being ranked third in the world. As an exporting country for bamboo products with a market share of 7 percent and the largest export value of USD 490 or around Rp. 6 trillion. In 2019, Indonesia exported a total of 52.306 metric tons of bamboo products, which had a total value of approximately USD 137 million. The majority of these exports were bamboo furniture, followed by bamboo handicrafts and bamboo flooring. In order to cope with the increasing demand for export, bamboo industries in Indonesia needs to do improvement in process time and quality control of the bamboo product that will be exported. An example of an action to solve this problem is by using specific machinery to improve the production time of a bamboo product, which means the bamboo industry in Indonesia needs a reliable machine to work with. Unfortunately, the current machine that is available on the market is unreliable.

The current machine is having several issues regarding the durability aspect of the bamboo splitter machine that is commonly used in the industries that work with bamboo. This is quite a problem because, several of the components of that machine is frequently replaced because of the design factor and the high impact when splitting the bamboo, some of the components are bearings, chain, and shaft holder. Other issues are because of the high impact force of the machine when splitting a bamboo, some parts are damaged and wear out resulting in the need for frequent replacement. Based on the observation researcher found out that using Quality Function Deployment is the suitable method to solve the problem, mainly Quality Function Deployment is heavily based on customer needs/requirements, so the problem can be solved with help from the voice of customers.

This research is aimed to help producer/industry to design a specific type of machine to improve the current production rate by using QFD (Quality Function Deployment) Method, QFD method is the method to develop a product based on the voice of customer of the product. According to Yoji Akao (1990) the founder of QFD, QFD is a methodology to translate the needs of the customer to design a product that is based on what the customers want and needs. The QFD technique may bring value to businesses since it gives them a competitive edge by

identifying the wants of consumers for their products or services (Akao, 1990). In this instance, a gadget is designed using the QFD approach as a foundation.

The output of this research will be an improvised design of the currently available bamboo splitter machine that is commonly available in the market. And hopefully can be a reference for further research on the same topic.

1.2 Problem Formulation

The objective to be achieved in this research will be mentioned below:

1. What is the customer's preference for the machine?
2. How to design the bamboo splitters machine?

1.3 Research Objective

The objective to be achieved in this research will be mentioned below:

1. Identify customer preference for the machine.
2. Determine the specification and design a new machine to process bamboo fencing.

1.4 Scope of Research

There are several limitations of this research, and it will be mentioned below:

1. The research is conducted in bamboo-related industries in Yogyakarta.
2. The method used in this research is QFD (Qualitative Function Deployment).
3. The data were gathered by conducting interviews and observation in bamboo-related industries in Yogyakarta.
4. The result of this research will be provided as recommendations and suggestions for future research.

1.5 Benefits of Research

The benefits of this research will be mentioned below:

1. For students, this research can help students to be familiar with the application of the theory and its relevance, also students can develop and apply their knowledge from class to solve a real problem in a company.

2. For the university, this research can be material for reviewing the student learning objective in the university, whether the current curriculum is still compatible with current real-world problems.
3. For further researchers, this research is expected to become a future reference.

CHAPTER 2

LITERATURE REVIEW

2.1 Inductive Study

Several previous studies have applied the QFD for several case studies, such as:

Arohman (2020) conducted research on the development of a specialized rice cooker designed for low-glucose rice, aiming to reduce the risk of diabetes among Indonesian individuals who consume rice on a daily basis. The rice cooker utilizes centrifugal force and heat to break down starch and separate glucose from it, effectively lowering the glucose content in rice. The methodology employed to design this low-glucose rice cooker is Quality Function Deployment (QFD), which enables the researcher to understand the customers' wants and needs for the rice cooker's design. To gather data, the researcher distributed a questionnaire to 30 respondents who own and use rice cookers in their daily lives. The findings resulted in a rice cooker with dimensions of 26cm in height, 27cm in diameter, a handle length of 16cm, and a handle width of 4cm. This rice cooker incorporates a centrifuge system and a heater that can reduce the glucose level in rice to 10% of a 10g sample of white rice. The operational process of the device involves a rotation speed of 200rpm and a temperature of 50 degrees Celsius, lasting for 20 minutes.

Dagri (2018) conducted a research project focused on developing and designing a rotary dryer-type sago grater machine that aligns with consumer preferences. The research employed the methodology of Quality Function Deployment (QFD), along with validity and reliability tests, a morphological chart, and the use of Solidworks 2013 software for the design process. After data processing, six key attributes were identified: capacity, color, content, water, design, and drying function, along with an additional draining function. The outcome of this research resulted in a machine that significantly reduces the drying time from 8.3 hours (for 15 tons) to just 2 hours (for 2 tons), while also decreasing the required workforce from 3-7 individuals to only 2 people.

Anugrah (2022) conducted a research study aimed at identifying the product packaging criteria desired by consumers, developing a packaging prototype, and assessing consumer feedback on the developed packaging. The researcher employed Quality Function Deployment (QFD) as the research method, which involved creating a House of Quality table to compare the selected criteria. The Kano model was also utilized to evaluate consumer satisfaction with the packaging, using Blauth's Formula. From this research, a total of eight criteria were offered

to the respondents, and seven criteria were selected based on their responses. The selected criteria, along with the corresponding number of respondents who chose them, are as follows: "Praktis" (Practical) with 90 respondents, "Penyajian Cepat" (Quick Presentation) with 59 respondents, "Menarik" (Attractive) with 61 respondents, "Efektif" (Effective) with 78 respondents, "Kualitas Terjaga" (Maintained Quality) with 91 respondents, "Terjangkau" (Affordable) with 67 respondents, and "Mudah Digunakan" (Easy to Use) with 62 respondents.

In 2022, Nurzikiresa conducted a research project aimed at designing an ergonomic carrying device using the House of Quality matrix. The research utilized Quality Function Deployment (QFD) with an anthropometric approach. The objective of the research was to develop a carrying device design that is easy to use, comfortable, and durable. Based on the specifications derived from the Quality Function Deployment (QFD) analysis, the device was designed to incorporate an Arduino UNO R3 minicomputer with elevated (green) and lower (red) buttons, along with a 300 cm high lever frame. The device also featured a handle with dimensions of 88.32 cm in length and 35.75 cm in width, with a handle diameter of 4 cm and finger joints measuring 2.25 cm in length. The haul base measured 200 cm in length and 100 cm in width, while the trolley was equipped with 10 cm rubber wheels. The base of the device measured 200 cm in length, 100 cm in width, and 15 cm in height. Stainless steel was chosen as the material for the device frame, and the handle was sleeved with rubber for enhanced grip and comfort.

In 2021, Haddade conducted research intending to reduce complaints and improve the quality of sago products in the regions of South and Southeast Sulawesi. Sago is a staple food in this area, and traditionally, the locals have been consuming wet sago, which is prone to spoilage. To address this issue, the researcher aimed to design a sago drying machine. The research sought to determine the extent of quality improvement in sago flour using Quality Function Deployment (QFD) and to assess the effectiveness of the new machine. The research began by gathering the voice of the customers to understand their preferences and needs. These inputs were then compared to the attributes that were currently not available in the existing machines. The research findings revealed the presence of 13 attributes in the improvement of this sago drying machine. These attributes include “*Alat awet dan kuat*” (Durable and sturdy device), “*Tidak mudah berkarat*” (Corrosion-resistant), “*Mudah dioperasikan*” (Easy to operate), “*Mudah dibersihkan*” (Easy to clean), “*Mudah dipindahkan*” (Portability), “*Mudah diperbaiki*” (Ease of repair), “*Daya listrik rendah*” (Low power consumption), “*Harganya dapat dijangkau UMKM*” (Affordability for SMEs), “*Pengering dan pengayak tertutup*”

(Closed drying and sieving system), “*memiliki control suhu*” (Temperature control), “*dimensi alat berukuran sedang*” (Medium-sized device dimensions).

Sutrisno, et.al (2021) performed a study to develop a bamboo splitter device for a village in Yogyakarta where many residents work as craftsmen of a *Besek* weaving. These craftsmen have been using traditional tools to manually split bamboo into thinner strands, which is a time-consuming and labor-intensive process. To address this issue, the researchers aimed to innovate the bamboo splitting process by creating a bamboo splitter device that would expedite the process and improve the productivity of the craftsmen. The implementation of the research consisted of three stages: the design stage of the tools, the material selection stage, and the manufacturing stage. Based on simulations, the resulting bamboo splitter device was capable of splitting bamboo into eight thin sections.

Sutanto et al. (2019) conducted a research project with the objective of developing a machine to enhance the production process, particularly in the areas of bamboo splitting and refinement. The aim was to enable faster production in the bamboo craft industry. To address this issue, the researchers designed a mechanical bamboo splitter and refiner machine. Considering the local conditions, the researchers prioritized a mechanically operated machine that does not require electricity, is easy to maintain, and requires minimal effort. The outcome of this research was the development of a machine for splitting and refining bamboo without the need for electricity, operating purely through mechanical means. This machine is capable of completing the split and refines process in just 5 seconds per bamboo.

Prabowo and Zoelangga (2019) conducted a research study aimed at developing a portable power charger. The research utilized Quality Function Deployment (QFD) as the method for the development process. A Voice of Customer questionnaire was employed to gather data and obtain feedback from potential customers. Based on the research findings, a design for a portable charger was developed, featuring dimensions of 15cm in length, 8cm in width, and 3cm in thickness. Additionally, an adhesive with a length of 25cm was incorporated into the design..

In 2017, PZ and Suparti conducted a research project aimed at developing tofu sieve equipment. The research utilized Quality Function Deployment (QFD) and Anthropometry in the development process. The background of the research was the recognition that the sieving process for tofu could be hazardous and potentially injure workers' hands due to the hot steam emitted from the soy porridge. The objective of the research was to prevent worker injuries and

reduce fatigue levels. The outcome of the research was the development of a machine that significantly accelerated the sieving process, reducing the time required from 14.38 minutes per sieving to just 6.5 minutes per sieving. Additionally, the energy consumption was reduced from 1.75-kilo calories to 0.26-kilo calories per minute.

Siregar et al. (2017) conducted a research study focused on improving the quality of care in hemodialysis facilities through the utilization of Kansei Engineering, Quality Function Deployment (QFD), and TRIZ in the design of haemodialysis machines. Kansei Engineering was employed to ensure that the service evokes the desired emotional response. Subsequently, QFD was utilized to enhance customer satisfaction by improving the quality of haemodialysis facility services. The research revealed that the repair and maintenance service of the machine needs to balance the alertness of medical staff with the cleanliness and comfort of the facility, as identified through the QFD analysis. The findings demonstrated that haemodialysis patients require a pleasant environment created by physicians, nurses, and receptionists, along with well-functioning haemodialysis machines and equipment.

In 2017, Wijaya and Larasita conducted a research study with the objective of designing an ergonomic bench to improve work posture and reduce musculoskeletal disorder (MSD) complaints among the batik producers of the Berkah Lestari batik group. The dimensions of the chair were determined using an anthropometric approach and modified design principles. Various measurements such as popliteal height, popliteal buttocks length, hip breadth, sitting shoulder height, and sitting elbow height were taken into consideration. The working posture was evaluated using the Rapid Upper Limb Assessment (RULA) approach, and the amount of MSD complaints were assessed using the Standardized Nordic Questionnaire (SNQ). Based on the anthropometric calculations, the planned chairs were designed with a seat mat height of 34.54 cm, length of 33 cm, and width of 44.19 cm at an angle of 50 degrees. The backrest measured 51.75 cm in height and 44.19 cm in breadth, with a slope of 1000. The hand support height from the seat was 18.28 cm, and its length was 25 cm. A comparison of the final RULA and SNQ scores revealed an improvement in work posture and a decrease in MSD complaints. This indicates that the designed chair can enhance body posture, providing a more pleasant and ergonomic seating option compared to the original chair used by batik producers.

In 2020, Lestari and Imtihan conducted a research study aimed at developing aquascape items that align with consumer preferences to enhance production. The research utilized the Quality Function Deployment (QFD) technique, which involved the implementation of

aquascape product design based on a matrix of customer demands. The study identified nine criteria with the highest importance, as determined by customer preferences: multifunctionality (5.00), durability (4.00), energy savings (4.00), innovation (4.00), a durable lamp (3.00), adjustable size (3.00), light weight (3.00), a distinctive form (3.00), and aesthetic value (2.70). Based on these criteria, the design priority was given to a multifunctional aquascape product known as "3in1." This design aimed to integrate three functions into a single product. Firstly, it included LED lamps with a total power of 57.6 W to provide illumination for the plants, simulating natural sunlight. The number of LED lamps used depended on the size of the aquarium. Secondly, the product featured an 8" DC fan to maintain a stable water temperature within the range of 25-27°C while conserving energy. Finally, the aquascape item served as a decorative element for the room, incorporating innovative design elements such as a bridge structure adorned with acrylic ornaments. By incorporating these features into the aquascape items, the research aimed to meet customer demands and enhance the production of aquascape products.

In 2020, Hasibuan and Sutrisno conducted a study aimed at enhancing community participation and comfort by designing shelters that aligned with the community's preferences. The study utilized the Quality Function Deployment (QFD) method to identify the desired features for shelter design. The implementation of QFD resulted in the identification of the following customer preferences for shelter design: Stop Size (7 x 3 x 4) m, bus stop lights 3 pieces, Stop using red and blue paint, Size of the stairs is 12cm in height and 30cm in width, Cast-concrete skeletal material, Stainless-steel seating material that provides route and pricing information, as well as route and price information. Overall, the aim of the study was to design shelters that meet the community's desires, promoting community participation and enhancing comfort by considering their preferences for size, lighting, aesthetics, staircase dimensions, and materials used.

Azwit et al. conducted a research study utilizing the Quality Function Deployment (QFD) technique and Rapid Entire Body Assessment (REBA) to improve the process of installing truck tires. Through interviews and direct observations, it was found that operators experienced symptoms of cumulative trauma disorder (CTD), particularly in the lower back region, due to an unnatural posture during manual material handling. One of the main causes of discomfort was the lifting and holding of heavy truck tires with specific dimensions: a diameter of 1.2 meters, a height of 0.3 meters, and a weight of 90 kilograms. To address this issue and enhance the installation process, a combination of the REBA, Nordic Questionnaire,

and QFD techniques were employed for analysis and product design. The outcome of the research was the development of a material-handling device that significantly reduced the occurrence of CTD. As a result, the ergonomic problem was successfully resolved, leading to a decrease in the risk and symptoms of CTD. The REBA score, initially indicating an extremely high risk at level 11, was reduced to a moderate risk at level 7. Similarly, the Nordic results showed a decrease in discomfort from seven body parts to only one body part.

In 2022, Muis et al. conducted a study with the aim of developing an Auto-Adjustable Desk to address the ergonomic issues associated with existing desks that lead to increased fatigue among workers, particularly in the shoulders. The objective was to create a desk that would provide convenience, comfort, and reduce fatigue during work. The Auto-Adjustable Desk was designed to allow workers to assemble multiple components simultaneously without the need to change positions. The implementation of the Quality Function Deployment (QFD) methodology was utilized as an industry-standard approach for product development. This approach focuses on translating customer requirements and desires into actual products by incorporating their preferences into the final product. To ensure the accuracy and objectivity of the data, measurements were conducted on thirty individuals. The ergonomic design and implementation of the desk were guided by the 12 ergonomic principles of the ENASE factor, which include effectiveness, comfort, safety, health, and efficiency. The validity and consistency of the collected data were assessed to ensure objectivity. Normality testing, data uniformity, and percentile measurement were performed to determine if the data followed a regular distribution and were uniform. By employing this distribution strategy, auto-adjustable desk products could be developed to meet ergonomic standards, providing efficiency and safety for users.

In 2017, Lee et al. conducted a study with the aim of improving the quality of Smartwatches and addressing the confusion among customers regarding the benefits and functionalities of these devices. The research recognized the need for Smartwatch manufacturers to understand and meet consumers' expectations by providing features that satisfy their needs. To achieve this, the study proposed the use of Quality Function Deployment (QFD), a method that integrates consumers' evolving requirements with product design. The QFD approach was implemented using a House of Quality (HOQ) matrix diagram, which allows for the representation of the relationship between consumer requirements and the design attributes of the Smartwatch. To gather data, a questionnaire-based survey was conducted to analyze the unmet and uncovered needs of consumers regarding Smartwatches. The opinions

of both consumers and technicians were collected and examined. Based on the survey results, a HOQ diagram was constructed to evaluate the correlation between the design attributes and technical attributes of the Smartwatch. Finally, the study identified the attributes that needed improvement and listed them in a suggested order of priority. This approach provided valuable insights for manufacturers to focus on enhancing the design attributes of Smartwatches that were most important to consumers, ensuring that their needs and expectations were met more effectively.

In 2022, Adefris conducted research focused on the utilization of contemporary technology in the field of forest tree processing machinery, specifically a bamboo splitting machine. The research aimed to develop and evaluate a bamboo splitting machine that could be used for constructing small dwellings, traditional house equipment, and fences in both rural and urban areas of Ethiopia. To understand the existing challenges in bamboo splitting operations and the need for such equipment, various data collection methods were employed. The design analysis involved examining the geometric components, determining the operational power requirements, and assessing the stress, forces, and deformation of each component. Pro-Engineer software was utilized to generate detailed part drawings and assembly diagrams. The selection of materials for the machine was based on criteria such as accessibility, affordability, utility, and durability. The splitter machine was designed to be fed intermittently through a chain drive system, consisting of a motor, a tool rest, a cutter-head, and blades or a cutting die. A guide rail was set on the tailstock to ensure proper alignment. With its innovative design and development, the bamboo splitting machine is capable of splitting bamboo culms up to 2.5 meters in length and 120 millimeters in diameter, using various strap sizes. The new machine offers improved efficiency compared to the previous method as it eliminates monotony, reduces operating time, and results in a more even surface finish of the split bamboo. Overall, this research contributes to the advancement of bamboo processing technology, providing a more efficient and effective solution for bamboo splitting operations in Ethiopia's rural and urban areas.

In 2018, Ahmed and Singh conducted research focused on designing and manufacturing a bamboo processing machine that serves three functions: splitting, grinding knots, and smoothing bamboo surfaces. This machine offers a solution to the labor-intensive and time-consuming manual processing of bamboo. It allows three individuals to work simultaneously, improving productivity. The tail stock of the machine is designed with a weight-adding chamber to facilitate the splitting process. Additionally, the machine can grind exterior knots

and utilize a sand belt to sand or polish the bamboo surface, removing both the outer and inner parts of the bamboo before applying ink or varnish. The key aspect of this machine is that it combines three functions into a single device, eliminating the need for separate machines for each purpose. While previous bamboo processing machines have been developed, this machine stands out for three reasons: firstly, it serves three distinct functions; secondly, it is constructed using locally available materials; and thirdly, it is cost-effective. There was a high demand for such equipment, addressing the challenges faced by bamboo furniture workers. It significantly reduces the labor-intensive manual tasks involved in bamboo processing and saves time. Moreover, it facilitates the production of high-quality goods. Considering that wood resources are depleting and wooden goods are more expensive compared to bamboo, the use of bamboo in furniture manufacturing is preferred. The constructed bamboo processing machine successfully performs manual bamboo splitting, bamboo knot grinding, and bamboo surface sanding, providing an efficient and effective solution for bamboo processing.

In 2020, Aravind et al. conducted research that proposed the design and production of a bamboo slicing machine. This machine has the capability to crosscut, split, and slice bamboo, aiming to fulfill all these processes in one device. One of the main objectives of this project was to develop a machine that could effectively slice bamboo along its length, resulting in multiple slices. The machine consists of several key components, including hardened and ground chisels, the table, the motor, and the base. These components work together to create a versatile machine that can effectively cut bamboo into various shapes. This equipment is suitable for working with ornamental wood and can be utilized by both small and large-scale wood enterprises. It finds applications in the production of several ornamental items. The introduction of this bamboo slicing machine offers a convenient and efficient solution for processing bamboo, providing greater flexibility and productivity in working with this material.

In 2019, Rusdi and Mastang conducted research focused on designing and manufacturing an improved bamboo splitting tool that could effectively double the splitting rate. The conventional method of physically splitting a 2-meter-long bamboo took approximately 15 seconds while using the existing equipment (cutting the bamboo in half) reduced the time to around 7 seconds. The researchers developed a cutting/splitting component consisting of four circularly arranged cutting blades that were welded together. The bamboo to be split was fed and guided towards this cutting component. The driving motor used for the tool was a 5.5-horsepower gasoline motor. The results of the study demonstrated that the new

tool could split a 2-meter-long bamboo into four pieces in approximately three seconds. In conclusion, the developed tool was found to split bamboo 4.67 times faster than the previous tool, significantly improving the efficiency of the bamboo splitting process.

In 2020, Gutha and Krisnaputra conducted a study focusing on the design of a bamboo splitter's frame, as there have been limited advancements in bamboo splitting machine technology. Several countries have developed technologies for bamboo splitting machines that offer improved efficiency, productivity, and durability. The quality of the machine is influenced by its design and weight, with the frame playing a crucial role in determining the machine's weight and efficiency. In the study, the researchers utilized AISI 304 hollow square steel for the machine frame and ASTM A36 wide flange beam steel for the machine buffer frame. To evaluate the frame design, calculations and testing were performed using the Finite Element Method (FEM). Solidworks, specifically the 2018 version, was used to conduct calculations and testing, considering various factors such as mass, volume, stress, displacement, and safety aspects. The test results provided insights into the maximum and minimum stress levels, strain, and deflection of the frame. The stress analysis for the machine frame revealed a maximum stress value of 32,172 MPa, which is within the yield strength of the material at 206.8 MPa. For the machine buffer frame, the maximum stress value was 0.113 MPa, while the yield strength of the material was 250 MPa. These test findings were essential in assessing the compatibility and durability of the frame for future use. By analyzing stress levels and ensuring they are within the acceptable range, the researchers could evaluate the frame's performance and its ability to withstand the demands of the bamboo splitting machine.

In 2021, Nugraha and Wismo conducted research focused on analyzing the design of the bamboo splitter blade. The study involved designing and analyzing the splitting knife component with three different sharpness angles: 22.5°, 45°, and 67.5°. The design approach aimed to create a "plug and play" concept for the splitting knife, with a statistical knife being the type of knife used. The component consisted of eight blades that could generate bamboo strips with a minimum width of 3 centimeters. After analyzing various mechanical and design safety aspects, it was determined that the 45-degree angle of sharpness was optimal. The splitting knife component was manufactured using ASTM A36 steel, which had a material wear rate of 30,173 mm³ per working hour based on Ogoshi method testing. To further evaluate the performance and safety of the knife component, CAE simulation using Finite Element Method (FEM) analysis modeling in Solidworks 2018 software was conducted. The simulation results showed that the knife component with a 45° sharpness angle on the bamboo splitting machine

remained safe when subjected to a load of 716 N from the pusher system. The factor of safety value was calculated to be 20.9, indicating that the component had a significant safety margin. Overall, the research provided insights into the design and analysis of the bamboo splitter blade, highlighting the optimal sharpness angle and confirming the safety of the knife component under specified loads.

The table below is a summary of all of the research above:

Table 2.1 Summary of previous studies

Number	Authors	Years	Object/Subject	Review			
				QFD	FEM	Exploratory	Others
1	Arohman	2020	Rice	V			
2	Dagri	2018	Sago	V			
3	Prabowo and Zoelangga	2019	Portable Charger	V			
4	PZ and Suparti	2017	Tofu siever	V			
5	Nurzikiresa	2022	Ergonomic carrying device	V			
6	Anugrah	2022	Coffee packaging	V			
7	Haddade	2021	Sago	V			
8	Sutanto, et.al	2019	Bamboo				V
9	Sutrisno, et.al	2021	Bamboo splitter				V
10	Siregar, er.al	2017	Haemodialysis machine	V			
11	Wijaya and Larasita	2017	Ergonomic Stool	V			
12	Lestari and Imtihan	2020	Aquascape tools	V			
13	Muis, et.al	2022	Ergonomic Table	V			
14	Lee, et.al	2017	Smartwatch	V			
15	Rusdi and Mastang	2017	Bamboo				V
16	Adefris	2022	Bamboo splitter				V
17	Hasibuan and Sutrisno	2020	Bus Shelter	V			
18	Ahmed and Singh	2018	Bamboo			V	
19	Aravind, et.al	2020	Bamboo				V
20	Gutha and Krisnaputra	2020	Bamboo		V		
21	Nugraha Wismo	2021	Bamboo		V		
22	Verrel Imansyah P.	2023	Bamboo splitter	V			

2.2 Deductive Study

2.2.1 Quality Function Deployment (QFD)

QFD, also known as Quality Function Deployment, was originally developed by Yoji Akao in Japan during the 1960s and 1970s. According to Akao, QFD is a methodology used to create a design quality that meets customer satisfaction by converting customer demands into specific design objectives and critical quality checkpoints that guide the entire production process. In the 1980s, the popularity of QFD grew significantly, expanding its reach to the United States, various industries, and multiple countries. Sullivan (1986) provides a definition of QFD as a comprehensive concept that facilitates the translation of requirements into relevant technical specifications for each stage of product development, including product design, engineering, prototype evaluation, marketing strategies, planning, production process development, production, and sales.

The core principle of QFD revolves around the creation of superior products that meet or exceed customer expectations through the collection and analysis of customer feedback. Consequently, the primary objectives of QFD include product development, quality management, and understanding customer needs. Over time, the scope of QFD has expanded to encompass a broader range of responsibilities, such as design, planning, decision-making, engineering, management, collaboration, scheduling, and costing. In essence, the utility of QFD is considered boundless (Chan, 2002). Hauser and Clausing (1988) state that Quality Function Deployment (QFD) focuses on organizing and mobilizing the talents within an organization to design, manufacture, and sell products that align with consumer preferences and sustain continued demand.

QFD is characterized by several key features. Firstly, it places a strong emphasis on fulfilling customer requirements by incorporating their explicit statements, often referred to as the Voice of the Customer. Secondly, QFD promotes multidisciplinary teamwork, encouraging collaboration across different departments and disciplines. Lastly, QFD utilizes comprehensive matrices to document information, perceptions, and decisions (Lowe, 2001). Temponi et al. (1998) highlight that QFD employs multiple matrices to establish clear connections between various aspects of a company's operations and customer satisfaction. These matrices are built upon the foundation of the "what-how" matrix, also known as the House of Quality (HOQ). The HOQ (House of Quality) graph is shown below.

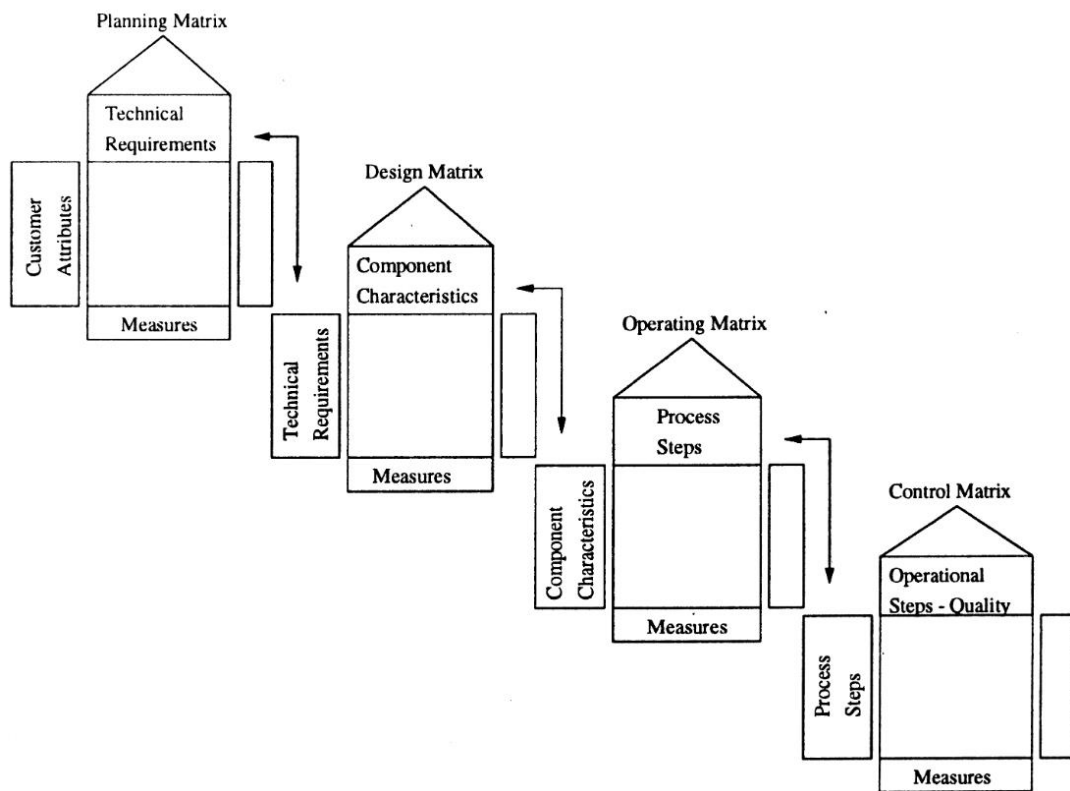


Figure 5.1 The phases of QFD

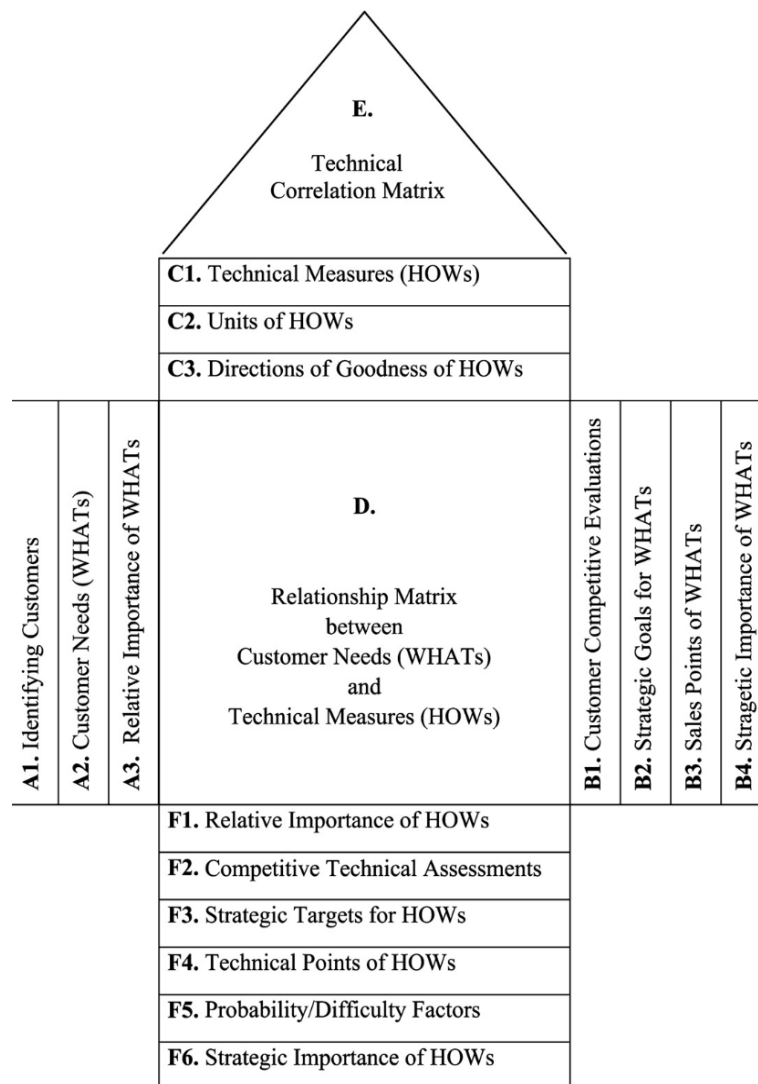


Figure 5.2 House of quality matrix

A.1 Part A Customer Needs (WHATs)

Quality function deployment starts with the customers. The first step for a development team of a company to build an HOQ is to identify the customers of the product, collect their

needs for the product (and, if necessary, organize these needs in the form of a tree diagram (Griffin 1993)), and reveal the needs' relative importance perceived by the customers.

A. A1. Identifying Customer

The process of identifying customers should begin by considering the specific characteristics of the product. Customers can be categorized into different groups based on their relationship to the organization. Internal customers consist of shareholders, managers, and employees, while intermediate customers include wholesalers and retailers. Final customers refer to the end-users, including service users, purchasers, and institutional buyers. The main attention is usually directed towards the final customers, and their identification can be achieved through analyzing historical data and conducting market research.

B. A2. Customer needs

Once the customers have been identified, the next step is to determine their specific needs for the product in question. Typically, customer requirements are expressed in their own words, and companies can gather this information through various methods conducted by their marketing department or an external market research firm. The American Supplier Institute (1994) and Bicknell and Bicknell (1995) provide a list of techniques for determining customer needs, which include:

- Surveys: Conducting mail or telephone surveys, comment cards, or questionnaires to gather customer feedback.
- Focus groups: facilitator guides a small group of 8-12 randomly selected customers for a free-flowing discussion of the products.
- Individual interviews: In a focus group, the views of the more outspoken participants may be reinforced, while the requirements of the more subdued participants may be overlooked. Individual interviews can overcome this deficiency and are highly successful in uncovering the emotional aspect of a customer's purchasing decision.
- Product in use: Observing customers using the product through displays or clinics to gain direct insights into their experiences.
- Listening and observing: At trade exhibitions and retail locations, managers, engineers, and "mystery shoppers" can be stationed to listen to people's comments and conversations. By studying clients, one can determine where they are confused, frustrated, or "lost" and then identify chances for "excitement."

- Natural field contact: Gathering insights from sales meetings, service calls, and trade shows where interactions with customers occur naturally.
- Feedback: Encouraging discussions between employees and customers about competitors' products to gain valuable insights.
- Complaints: Collecting customer complaints through letters, cards, or hotlines to identify areas of dissatisfaction or issues requiring attention.
- Warranty data: Analyzing service records, warranty cards, and letters to gain insights into product performance and customer experiences.
- Sales records: Reviewing monthly reports and analyzing part sales data to understand customer purchasing patterns.
- Publications: Referring to government publications, independent lab reports, trade journals, and consumer magazines for industry insights and consumer feedback.

By employing these techniques, companies can effectively gather customer input and better understand their needs and preferences.

C. A3. Relative Importance

The subsequent step in QFD involves determining the relative importance of the identified customer demands, as not all customer needs carry the same level of significance. To optimize resource allocation, companies prioritize the most critical customer wants while disregarding less significant ones. Typically, customers are asked to rate the relative importance of each customer requirement, using scales such as five-point, seven-point, or nine-point scales. More elaborate scales like the 1-10 scale or anchored scale (Griffin, 1993) may also be used. Common methods for collecting this information include mail-and-telephone surveys, which are considered acceptable and cost-effective. Focus groups and individual interviews are generally unsuitable for gathering quantitative data on the relative importance of customer needs due to their higher costs and the need for large sample size for statistical significance. Additionally, fuzzy approaches can be employed to address the ambiguity and subjectivity inherent in people's evaluations (Chan, 2007). These approaches help to assign appropriate weights to customer needs based on their relative importance, facilitating effective decision-making in the subsequent stages of QFD.

A.2 Part B. Planning Matrix

This part consists of consumer competitive evaluations of the company's product in comparison to similar goods from its principal rivals, based on the items' success in meeting customer demands. Based on these comparative analyses, the corporation may establish strategic goals for its product to better meet client requirements. Additionally, sales points may be produced to reveal the competitive positions and prospects of a business.

A. B1. Customer Competitive Evaluation

In order to enhance competitiveness in the relevant markets, the company undergoing evaluation needs to identify its competitors who manufacture similar products. To gain a comprehensive understanding of strengths and weaknesses across all aspects of the product and its primary competitors, evaluative data is crucial. This data can be collected by asking consumers to rate the relative performance of the company and its competitors for each customer requirement (WHAT), and then aggregating the evaluations. Similar to Part A3, performance can be assessed using an appropriate numerical scale, and mail/telephone surveys remain effective methods for gathering this information. However, focus groups and individual interviews are still considered inappropriate for this purpose. It's important to note that customers should only rate products with which they have extensive experience. Consequently, a larger sample size is necessary to ensure statistical significance in order to preserve accuracy in the evaluations.

B. B2. Strategic Goals for WHATs

Once the performance of your company and competitors on each customer requirement has been assessed through customer competitive evaluations, the next step in QFD is to establish goals for each requirement (WHAT). These goals should be expressed numerically and align with the designated grading scale. It is essential to set realistic objectives that consider factors such as program timeline, available resources, cost objectives, and existing technology. According to Cohen (1996), the goal-setting strategy determines the course of action a company will undertake to better meet customer demands. These activities can include:

- Improve through QFD implementation: Implementing QFD processes and strategies to enhance performance and meet customer requirements more effectively.
- Hold (retain your present position): Maintaining the current level of performance and customer satisfaction without significant changes.

- Copy a competitor (not recommended): Attempting to replicate the performance of a specific competitor. However, this choice may not be ideal as it lacks originality and may not fully address customer needs.
- Degrade (potentially risky): Deliberately lowering the performance level to match a customer's demand. This approach can be dangerous as it may exceed a customer's expectation, leading to dissatisfaction.

Careful consideration should be given to selecting the appropriate goal-setting strategy that aligns with the company's capabilities, customer demands, and overall objectives.

C. B3. Sales Points of WHATs

After collecting the previous data, the next step is to determine the company's sales points for each customer need. A sales point represents the company's ability to market a product based on how effectively it addresses each customer requirement (Cohen, 1995). In other words, the sales point reflects the potential for the company to offer a unique selling proposition. When both the company and its competitors perform poorly in addressing a specific customer need (WHAT), it suggests a technological bottleneck, and the company requires a technological breakthrough to improve its product (ASI, 1994).

Typically, a "strong" sales point is assigned to a customer need that is poorly addressed by competing companies. A "moderate" sales point indicates that the importance rating or competitive potential is not as significant, while a "no" sales point indicates no business opportunity. Numerically, strong sales points are designated with a value of 1.50, moderate sales points with 1.25, and no sales points with 1 (corresponding to the scale).

To provide a more objective representation of the competitive priorities of the customer needs, entropy approaches can be utilized to determine the significant weights of a set of decision qualities (Chan, 1997). These approaches assist in objectively highlighting the competitive priorities of the customer needs within the context of the overall QFD process.

D. B4. Strategic Importance if WHATs

The following formula can be used to calculate the strategic priority rating (or row total, planning weight, as some refer to it) for each customer needs based on the aforementioned data.

$$\text{Final importance} = (\text{goal} - \text{current position}) \times \text{relative importance} \times \text{sales point}$$

Customer requirements with a high final importance rating suggest a strong potential for business benefit to the organization and should therefore be prioritized.

A.3 Part C. Technical Measure (HOWs)

This stage involves listing and structuring the technical specifications (HOWs) identified by the product development team. Furthermore, it entails determining the units of measurement and the desired direction of improvement for these technical specifications. This information serves as a basis for further analysis, examination, and implementation in the QFD process.

A. C1. Technical Measures (HOWs)

In this phase, the customer requirements obtained through information gathering and analysis are translated into technical measures, known as HOWs. HOWs encompass methods, company measures, design requirements, alternative quality characteristics, and engineering specifications that can be linked to and measured against customer needs (WHATs). According to the American Supplier Institute (1994), effective HOWs should be measurable, comprehensive, and proactive. Technical metrics are often derived from existing product standards. To identify suitable HOWs, cause-and-effect diagrams or tree diagrams can be constructed, ensuring that the selected HOWs are the primary factors contributing to the customer needs through cause-and-effect analysis. Similarly, the Affinity Diagram approach, used in addressing customer needs, can be valuable in organizing the chosen HOWs into a hierarchical structure, facilitating analysis and implementation.

B. C2. Units if HOWs

Each measure in QFD should be accompanied by a specific unit and direction to ensure accurate definition. It is important to explicitly state these units in the QFD matrices for the sake of clarity and completeness. Units serve to quantify the measurements, while directions indicate the desired improvement or goodness associated with each measure. Examples of units that can be used in QFD matrices include volts for voltage, minutes for time, feet for length, pounds for weight and force, gallons for capacity, foot-pounds for energy, pounds per square foot for resistance, number of steps for process complexity, defects per thousand pieces or defects per million for quality, and so on. Explicitly specifying the units adds precision and facilitates a comprehensive understanding of the measures within the QFD framework.

C. C3. Directions of Goodness of HOWs

Cohen (1995) outlines three possible definitions for different HOWs regarding improvement directions. These definitions are as follows:

1. The more, the better (to increase): This implies that for certain HOWs, a higher value or quantity is considered desirable. In these cases, improvement involves increasing the measure to achieve better results.
2. The less, the better (to decrease): For certain HOWs, a lower value or quantity is preferred. Improvement in this context involves decreasing the measure to achieve better outcomes.
3. Target is best (to close to): This indicates that for specific HOWs, the measure should be as close as possible to a specific target value. Improvement entails narrowing the gap between the current measure and the desired target value.

By identifying the appropriate improvement direction for each HOW, the QFD process can establish clear objectives and guide efforts toward achieving the desired outcomes.

A.4 Part D. Relationship Matrix Between WHATs and HOWs

The Relationship Matrix of WHATs vs. HOWs is a crucial component of the QFD method, providing a systematic approach to assessing the strength of the connection between each WHAT (customer need) and each HOW (technical measure). The completion of this Relationship Matrix is an essential phase in the QFD process, as the intersection symbols or numbers in this matrix play a significant role.

It is recommended to fill up the Relationship Matrix column-wise or HOW-wise. In this approach, the development team identifies each HOW once and then assesses its contribution to meeting each of the WHATs. Alternatively, one can study the influence of each HOW on each WHAT and characterize the degree of influence as the connection between the two (Chan, 2007).

Typically, four levels of relationships are used: no relationship, weak/possible relationship, medium/moderate relationship, and strong relationship. To quantify these relationships, two sets of measurement scales are commonly employed: (0, 1, 3, 9) (Cohen, 1995) and (0, 1, 3, 5) (Hauser, 1988). The former scale is more frequently used and considered

more suitable, as it assigns a significantly higher weight to the strong relationship, which is particularly important in the product development process.

To intuitively represent the degrees of relationships between HOWs and WHATs, symbols are often used by QFD experts. The following set of simple symbols is suggested for representing the four levels of relationships: a blank space for "no relationship," Δ for "weak relationship," $\circ$ for "moderate relationship," and $\bullet$ for "strong relationship." These symbols aid in visually describing the connections between HOWs and WHATs within the Relationship Matrix.

A.5 Part E. Technical Correlation Matrix

The Technical Correlation Matrix in QFD is used to capture the development team's assessments of the correlations and strengths between different HOWs based on their engineering expertise and experience. This matrix is a valuable yet often underutilized aspect of QFD, as highlighted by Cohen (1995). Once the HOWs have been defined, the development team can analyze how changes in one HOW may impact the others. The Technical Correlation Matrix allows the team to identify the degrees and directions of these interdependencies, which can have significant effects on the overall development process. If one HOW negatively affects other HOWs, it indicates potential design bottlenecks that require specific planning or breakthrough attempts. On the other hand, positive correlations between HOWs can indicate areas of synergy or shared functionality. By analyzing the Technological Correlation Matrix, the development team can identify which technical domains require close collaboration and communication, and which ones do not. This insight helps in coordinating efforts and addressing potential conflicts or constraints in the development process. By effectively utilizing the Technical Correlation Matrix, a company can optimize its development strategies and foster efficient cross-functional collaboration among various technical disciplines.

The Technical Correlation Matrix in QFD typically considers five categories of technical correlations or impacts: strong positive impact, moderate positive impact, no impact, moderate negative impact, and strong negative impact (Chan, 2007). To visually represent these effects, a set of symbols, such as $\sqrt{\sqrt{}}$, $\sqrt{}$, (blank), $\times$, and $\times\times$, is commonly used. However, despite its potential benefits, the Technical Correlation Matrix is often underutilized in QFD research, with only a few studies quantifying the technical effects.

Exceptions to this underutilization include the works of Belhe and Kusiak (1996) and Khoo and Ho (1996), who go beyond symbolic representations and transform impact symbols into appropriate numerical scales. These studies explicitly incorporate the technical effects into the QFD process, providing a more quantitative and comprehensive approach to assessing the correlations and impacts between HOWs.

In summary, while the Technical Correlation Matrix has the potential to enhance QFD analysis, its practical implementation and quantification of technical effects have been limited in previous research. However, some studies have made strides in transforming impact symbols into numerical scales to better incorporate and evaluate the technical correlations in the QFD process.

As the Technical Correlation Matrix consists of elements above its diagonal, it graphically resembles the roof of a home, hence the name "House of Quality".

A.6 Part F. Technical Matrix

The Technical Matrix contains much technical information that is linked to both customer needs and parts characteristics in QFD's second phase. It provides the initial rank ordering of the technical measure's relative importance based on the information in the previous parts.

In the second phase of QFD, the Technical Matrix is utilized to establish connections between technical data, customer requirements, and component attributes. Based on the available data, this matrix provides an initial ranking of the relative importance of the technical measures. Competitive technical evaluations are conducted to assess how the company's performance compares to that of its competitors on the identified technical measures. This evaluation helps in determining strategic targets and assessing the probabilities or technical challenges associated with achieving these targets. By considering this information, the strategic or final importance of the technical measures can be computed. The most significant technical measures are then selected to proceed to the next phase of QFD for further analysis and implementation.

A. F1. Relative Importance of HOWs

The significance rating of each HOW is determined by considering its connection to all the WHATs and the final significance ratings of the WHATs. This rating represents the overall importance of the HOWs in relation to the WHATs. To calculate these ratings, a simple additive weighting algorithm is commonly employed, as suggested by Chan (2007).

$$\begin{aligned} &\text{The relative importance of HOW} \\ &= \sum [\text{final importance rating of WHAT} \times \text{relationship value between WHAT and the HOW}] \end{aligned}$$

In order to determine the relative relevance score of a HOW, the values of its relationships with each WHAT are averaged, taking into account appropriate weighting factors. This calculation method allows for the incorporation of the overall importance of the HOWs in relation to the WHATs. Additionally, Chan (1998) suggests that alternative decision-making and performance-measuring approaches can be utilized to calculate the relative relevance ratings of the HOWs, providing more sophisticated methods for assessing their significance.

B. F2. Competitive Technical Assessments

Once the relative relevance of the HOWs has been determined, it is important to conduct comparative technical evaluations to assess how your product's technical performance compares to similar offerings from competitors. Gathering information on the technical characteristics and expertise of competitors' products can be challenging, especially when using QFD, as some of this information may be sensitive or difficult to obtain. It may be necessary to purchase and test competitors' products in order to conduct a thorough evaluation. The development team must make maximum efforts to collect benchmark data, as failing to do so can result in a less competitive position in the market. In cases where it is difficult to obtain technical parameters of competitors' products for certain HOWs, detailed technical assessments and comparisons should be conducted to provide reliable scores, using a suitable scale consistent with customer competitive evaluations, to represent the technical performance of competitors' products on those specific HOWs.

C. F3. Strategic Targets for HOWs

After prioritizing the HOWs and conducting competitive technical evaluations, the next step is to establish performance objectives for each HOW. These objectives should be differentiated from design requirements. The performance objective for a HOW represents the desired level of performance on that aspect that the company deems necessary for its product

to be competitive in the relevant market, relative to its competitors. If a HOW is deemed highly relevant (indicating a significant impact on customer needs) and/or if the product's performance is lagging behind similar offerings from rivals, then the performance objective for that HOW should be set ambitiously high. Similar to how strategic objectives for customer satisfaction in Part B2 are aligned with the organization's technological capabilities, these performance objectives should also be realistic and aligned with the company's capabilities.

D. F4. Technical Points of HOWs

Although customer competitive evaluations and technical assessments of the competition are important, it is observed that only a small portion of QFD studies explicitly utilize this data to assess the ultimate strategic value of the HOWs. However, by combining competing technical evaluations and the relative relevance of the HOWs, it is possible to derive similar sales points as those determined for the WHATs (as discussed in Part B3). These sales points can be considered as technical points to provide clarity and categorization when determining the overall strategic significance of the HOWs.

E. F5. Probability and Difficulty Factors

The development team can determine a likelihood or difficulty factor for each HOW's performance aim through engineering and cost analysis. This factor represents the probability or level of difficulty associated with achieving the objective. Typically, an aggressive objective aimed at gaining a competitive advantage and higher profitability would have a low likelihood factor, indicating a higher level of difficulty. Conversely, a cautious target would have a high likelihood factor, suggesting a lower level of difficulty. It is recommended to use a scale consistent with earlier sections, such as a five-, seven-, or nine-point scale, where a larger number indicates a higher likelihood of achieving the objective.

F. F6. Strategic Importance of HOWs

The relative importance ratings of the HOWs determined in Part F1 are solely based on their relationships with the prioritized WHATs and do not consider the competitive technical assessments, performance targets, or probability factors discussed in the preceding parts (Parts F2-F5). These ratings reflect the core relevance of the HOWs. To obtain a comprehensive assessment of the value of each HOW, it is recommended to include an additional step in the House of Quality (HOQ) process, known as Part F6. This step computes the final importance rating for each HOW, taking into account various factors. Surprisingly, no previous QFD

research has extensively considered the final importance of HOWs as done in Part F6. Similar to determining the final significance of WHATs in Section B, the ultimate relevance of HOWs can be derived. Intuitively, HOWs with higher initial relative importance ratings (indicating stronger relationships with important WHATs), higher competitive priorities based on technical points or competitive technical assessments, larger performance gaps between current levels and target levels, and lower probabilities should have greater strategic significance. This helps to identify the company's focus areas and market opportunities. Consequently, they suggest the following formula to get the final significance score for each HOW:

$$\begin{aligned} \text{Final importance} = & (\text{target} - \text{current position}) \\ & \times \text{relative importance} \\ & \times \text{technical point} \\ & \div \text{probability factor} \end{aligned}$$

HOWs with higher ultimate relevance are selected and transitioned to Phase II of QFD, known as Parts Deployment. In this phase, these selected HOWs are treated as new WHATs, and their corresponding parts characteristics (new HOWs) are determined. The analysis and completion of this new phase follow the same process as outlined for the House of Quality (HOQ) in Parts C through F of QFD, as described by Chan in 2007.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Object

The research object of this research is to improve the efficiency of bamboo fencing production by designing a new type of machine to process the bamboo fencing. The methodology of research is using QFD to develop a new type of machine. The data of this research will be obtained by conducting observation and interviews in bamboo industries in the Yogyakarta area. This research is to improve the performance of the bamboo fencing assembly process in bamboo industries in the Special Region of Yogyakarta.

3.2 Research Instrument

The research instrument that will be used in this research is mentioned below:

1. Video camera, to record the assembly process of bamboo fencing.
2. Measurement tape, to measure the bamboo length and width.
3. Notepad, to record the measurement and the data obtained from workers.
4. Voice of Customer questionnaire, to get the data for the House of Quality (HOQ) table.

3.3 Data Collection Method

There will be two types of data that will be used in this research, primary, and secondary data.

1. Primary Data

Primary data is data gathered by the researcher itself, it can be done through observation, interview, or questionnaire. In this research the primary data will be an interview with the employee that works in bamboo-related industries, another data is the time needed to process the bamboo with current tools/machines.

2. Secondary Data

Secondary data is existing data that can be derived from the company or a research paper or journal. In this research, the secondary data will be the technical specification and measurement of the bamboo fencing.

3.4 Data Processing Method

This research will employ the House of Quality (HOQ) to process the data from the Voice of Customer, the House of Quality itself is using all of the houses which is, House 1 (Product Planning), House 2 (Assembly/Part Deployment), House 3 (Process Planning), House 4 (Process/Quality Control)

3.5 Research Flowchart

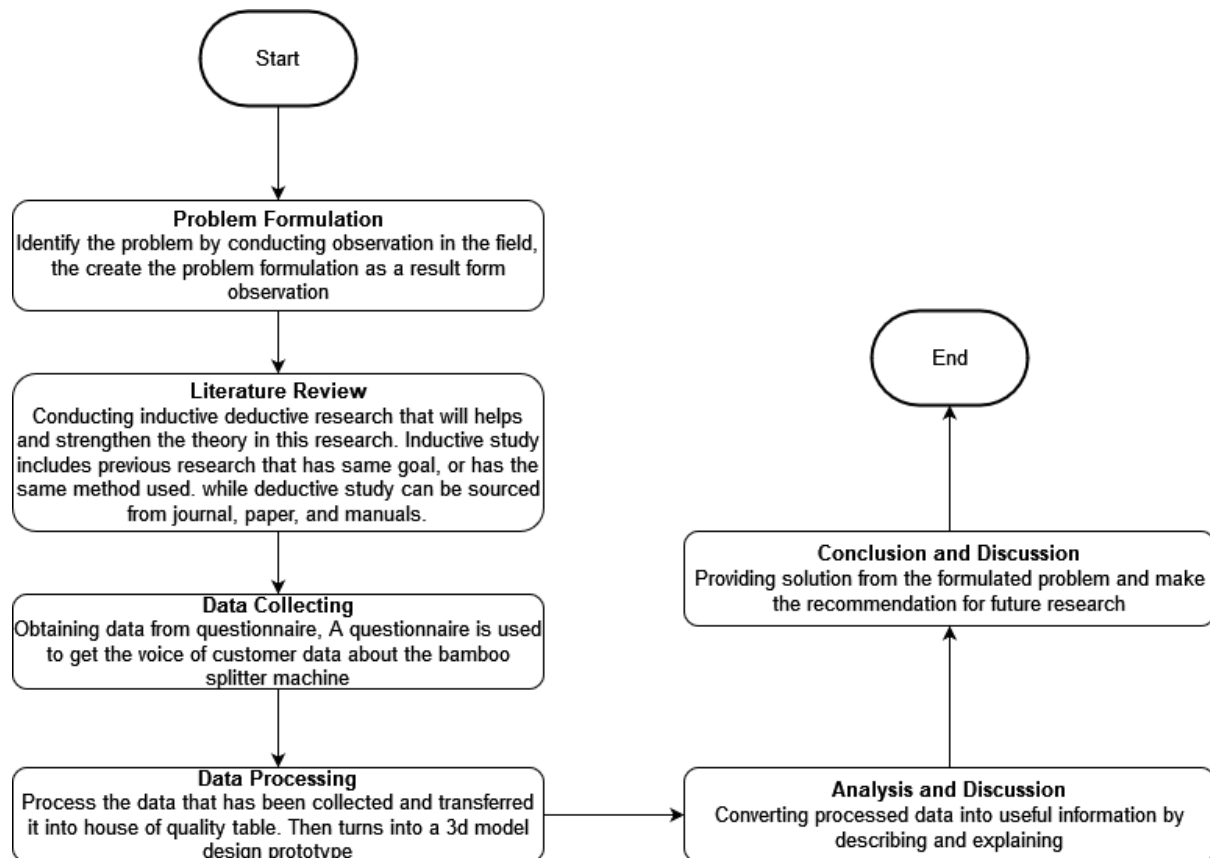


Figure 6.1 Research flowchart

The explanation of figure 3 above is mentioned below:

1. Problem Formulation

Problem formulation is the first step to start this research, before formulating the problem researcher should identify the problem by conducting observation in the field, then the problem formulation can be generated, as a result form observation.

2. Literature Review

The literature review helps the researcher to work on this research, the literature review also strengthens the theory in this research, it is categorized as:

a. Inductive study (preceding research)

The inductive study includes previous research that has the same goal or has the same method used.

b. Deductive study

The deductive study is the theoretical foundation for this research, deductive study can be sourced from journals, papers, and manuals.

3. Data Collection Using Voice of Customer

The data collection process is conducted using a Voice of Customer questionnaire, the questionnaire will be given to the worker in a bamboo-related industry in Yogyakarta.

4. Data Processing and Making the 3d Prototype.

This step is the process of developing the bamboo splitter machine by processing the data that has been collected which is the Voice of Customer data, that data will be transferred to the House of Quality (HOQ) table. Then the data is converted to a 3d design prototype using 3d modeling software.

5. Analysis and Discussion

In this step, the researcher is analyzing the House of Quality table, and designing the bamboo splitter machine based on the result of the House of Quality table. Also, the data will be compared with the current machine.

6. Conclusion and Recommendation

This is the last step that will answer the problem formulation and conclude the whole research. This step also includes a suggestion for the host company as well as for future research.

CHAPTER 4

DATA COLLECTING AND PROCESSING

4.1 Data Collecting

Data processing is carried out by conducting surveys, interviews, and a focus group discussion with people involve in the bamboo industry, to know what are the important feature that needed to be on the bamboo splitting machine. After the voice of customer data is gathered, that data is then transferred to the quality function deployment table, or known as the House of Quality table.

4.1.1 Problem Finding

The first step is to conduct the survey the industry that works with bamboo, to do observation and formulate any problem of the current bamboo splitting machine in that industry. When conducting the observation, the researcher identify several issues on the current machines regarding durability of the machine, because the impact force was so high when splitting the bamboo, many parts of the machine are replaced frequently like bearings that need replacement frequently one after another. Same as the chain to drive the pusher it has been changed 1 time that year. Another problem was also found in the part that connects the pusher with the chain, it also has been changed, and the slots themselves were also damaged as the result of the high impact forces. Below is a picture of the current bamboo splitter and its damaged parts.



Figure 0.1 Damaged pusher



Figure 0.2 Damaged “T207”

4.1.2 Voice of Customer

In this research, the researcher uses the voice of customer to find out what are the important features/factor needed on a bamboo splitting machine. To gather the voice of customers data,

the researcher creates a questionnaire and small interviews with person that involve in the bamboo industry, the question itself consists of 8 questions which are mentioned below:

1. Did process time of the machine is important? (Apakah waktu pengoperasian mesin penting?)
2. Did safety factor is important? (Apakah aspek keselamatan mesin penting?)
3. Did durability is important? (Apakah daya tahan mesin penting?)
4. Did precision of the machine is important? (Apakah tingkat presisi dari mesin penting?)
5. Did the machine need to be easy to operate? (Apakah mesin perlu untuk mudah dioperasikan?)
6. Did the customizable factor is important? (Apakah kustomisasi penting?)
7. Did affordability of the machine is important? (Apakah biaya produksi mesin yang terjangkau penting?)
8. Did the machine need portability? (Apakah mobilitas mesin dibutuhkan?)

4.2 Data Processing

In this section, the data that has been collected above will be processed with Quality Function Deployment method to translate customer expectations and needs from the voice of customers into a technical requirement. QFD is usually used as a tool to improve or develop a product based on the customer requirements or expectations, the output of quality function deployment is a table called house of quality, below is the house of quality table of this research.

4.2.1 Determination of the Customer Requirement

Based on the voice of customers data that has been collected then it is transferred to be the attributes in the customer requirement table, the following table is mentioned below.

Table 4.1 Customer requirements attributes

Customer needs	Sales Point
Process time	1,2
Safety	1,5
Durability	1,2
Precision	1
Easy to use	1,2
Customization	1,2
Affordability	1

4.2.2 Important Rating Calculation

Important Rating is determined to know the importance of each customer's requirements. To get the important rating value, the researcher use excels to process it, the result is mentioned below.

- Process Time data

The table below shows the important rating of the Process time attribute.

Table 4.2 Process time data

Process Time			
	scale	score	total
very important	5	16	80
more important	4	4	16
important	3	0	0
less important	2	0	0
not important	1	0	0
total		20	96
important rating		4,8	

- Safety data

Below is the important rating of the safety attribute table.

Table 4.3 Safety data

Safety			
	scale	score	total
very important	5	14	70
more important	4	6	24
important	3	0	0
less important	2	0	0
not important	1	0	0
total		20	94
important rating		4,7	

- Durability data

The table below is the customer's important rating of durability attribute.

Table 4.4 Durability data

Durability			
	scale	score	total
very important	5	14	70
more important	4	6	24
important	3	0	0
less important	2	0	0
not important	1	0	0
total		20	94
important rating		4,7	

- Precision data

Table below shows the important rating of precision attribute.

Table 4.5 Precision data

Precision			
	scale	score	total
very important	5	16	80
more important	4	4	16
important	3	0	0
less important	2	0	0
not important	1	0	0
total		20	96
important rating		4,8	

- Easy to Use data

Below is the important rating table of easy-to-use attributes.

Table 4.6 Easy to Use data

Ease to Use			
	scale	score	total
very important	5	13	65
more important	4	6	24
important	3	1	3

less important	2	0	0
not important	1	0	0
total		20	92
important rating		4,6	

- Customization data

The table below shows the important rating of the customization attribute.

Table 4.7 Customization data

Customization			
	scale	score	total
very important	5	13	65
more important	4	4	16
important	3	3	9
less important	2	0	0
not important	1	0	0
total		20	90
important rating		4,5	

- Affordability data

Below is the important rating of the affordability attribute table.

Table 4.8 Affordability data

Affordability			
	scale	score	total
very important	5	13	65
more important	4	6	24
important	3	1	3
less important	2	0	0
not important	1	0	0
total		20	92
important rating		4,6	

- Portability data

The table below shows the important rating of the portability attribute.

Table 4.9 Portability data

Portability			
	scale	score	total
very important	5	0	0
more important	4	0	0
important	3	5	15
less important	2	9	18
not important	1	6	6
total		20	39
important rating		1,95	

Below is the summary of all the important that has been gathered above.

Table 4.10 Customer requirement summary

Customer Requirements		
Number	Attributes	Important Rating
1	Process time	4,8
2	Safety	4,7
3	Durability	4,7
4	Precision	4,8
5	Easy to use	4,6
6	Customization	4,5
7	Affordability	4,6
8	Portability	1,9

4.2.3 Determine the Technical Requirements

After determining the important rating for each Customer Requirement attribute, the next step is to translate customer needs and expectations into Technical Requirements to know the technical criteria which will use to develop the bamboo splitting machine, below is the table that shows the Technical Requirements based on Customer Requirement attribute mentioned above.

Table 4.11 Technical requirement

No	Customer Requirement	Technical Requirement
1	Process time	Machine Rpm Machine Power Output
2	Safety	Machine Cover Emergency Button
3	Durability	Durable Material

4	Easy to Use	Machine Size Use Pushing Mechanism
5	Precision	Use Pushing Mechanism Add Guiding Rail
6	Customization	Interchangeable Blade
7	Affordability	Use Pushing Mechanism
8	Portability	Easy to Move

4.2.4 Determine the Target Value

The target value is determined based on the Technical Requirement which is already mentioned in the table above. Below is the Target Value determined to develop the bamboo splitting machine.

Table 4.12 Target specification

No	Technical Requirement	Target Specification
1	Machine Rpm	Moderate Rpm
2	Machine Power Output	Moderate Power Output
3	Machine Cover	Cover for Safety
4	Emergency Button	Emergency Button
5	Durable Material	Use High Carbon Steel
6	Machine Size	Sufficient size
7	Use Pushing Mechanism	Use a Pusher
8	Add Guiding Rail	Guide for Easy Operation
9	Interchangeable Blade	Blade Can Be Change
10	Easy to Move	Add Wheel

4.2.5 Relation Between Customer Requirement and Technical Requirement

After the value of Customer Requirements and Technical Requirements are gathered, the next step is to define the relationship between customer requirements and technical requirements. The relationship value can be determined using relationship level which is weak (1 point), Medium (3 points), and Strong (9 points).

<div>Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")</div> <div>Demanded Quality (a.k.a. "Customer Requirements" or "Whats")</div>	Machine RPM	Machine power output	Machine cover	Emergency button	Durable material	Machine size	Use pushing mechanism	Add guide rail	Interchange able blade	Easy to move
Process time	○	○					○	○	○	
Safety			○	○	○	○	○	○		
Durability					○		○		○	
Precision	○	○					○	○	○	
Easy to use						○	○	○		
Customization									○	
Affordability	○	○	○		○	○	○	○	○	
Portability			▲			○		▲	○	○

Figure 0.3 Relationship between the customer and technical requirement

4.2.6 Target Weight

Target Weight is processed to gather information and the level of product design development. The value in this row can be gathered by calculating the Important Rating and the value of the relation between Customer Requirement and Technical Requirement. Below is the row of Target Weight.

<div>Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")</div> <div>Demanded Quality (a.k.a. "Customer Requirements" or "Whats")</div>	Machine RPM	Machine power output	Machine cover	Emergency button	Durable material	Machine size	Use pushing mechanism	Add guide rail	Interchange able blade	Easy to move
Process time	○	○					○	○	○	
Safety			○	○	○	○	○	○		
Durability					○		○		○	
Precision	○	○					○	○	○	
Easy to use						○	○	○		
Customization									○	
Affordability	○	○	○		○	○	○	○	○	
Portability			▲			○		▲	○	○
Target or Limit Value	moderate Rpm	moderate power output	cover for safety	emergency button	high carbon steel	sufficient size	use a pusher	guide for easy operation	blade can be change	add wheel

Figure 0.4 Weight of each technical requirement

As we can see in the table above the most important target is “machine implement moderate technology”

4.2.7 Technical Correlation Matrix

This section is enumerating and organizes the technical requirements that have been determined by the researcher/team. The units and directions of goodness or improvement of the technical requirements are determined to help additional study. Below is the technical correlation matrix.

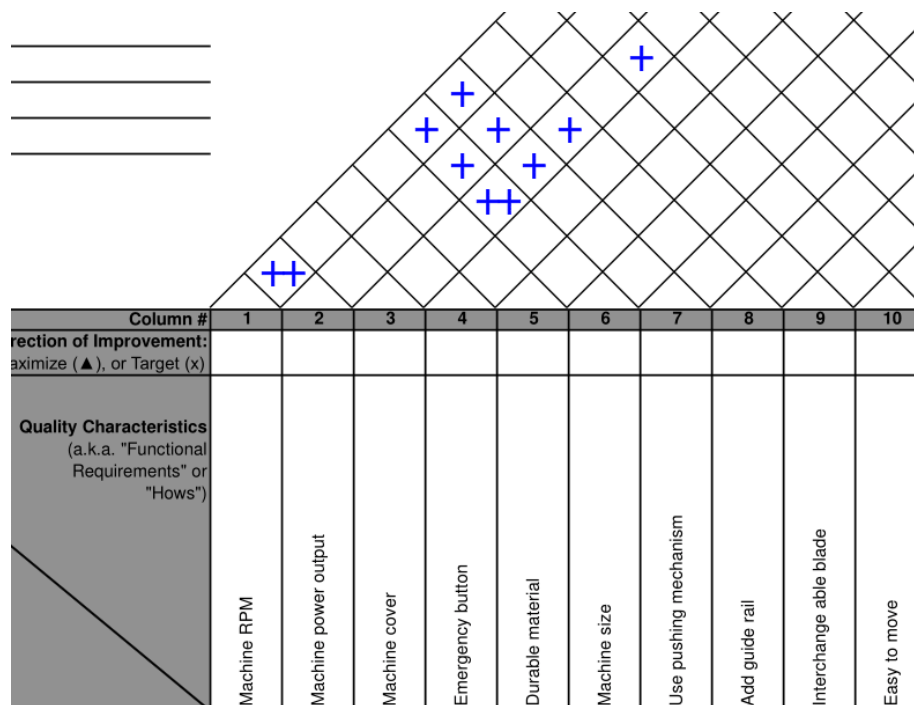


Figure 0.5 Technical correlation matrix

The picture above is the technical correlation matrix of this research. In this matrix, there are 4 types of correlation which are:

- ++ : strong positive
- + : positive
- : negative
- ▼ : strong negative

So, the technical characteristic that correlated in designing this bamboo splitter machine are mentioned below:

1. Strong material has a **strong positive** correlation with size.
2. Strong material has a **strong positive** correlation safety factor.

3. Strong material has a **positive** with implemented technology.
4. Size has a **positive** with safety factors.
5. Size has a **strong positive** with portability.
6. Power source a **strong positive** with implemented technology.

In this matrix also, we can see the directions of improvement which tells us the development planning of each technical requirement. There are 3 directions which are ▼ (the objective is to minimize), ▲ (the objective is to maximize), and X (the objective is to hit the target).

4.2.8 Customer Competitive Evaluation Calculation

The next step is to calculate the Customer Competitive Evaluation (CCE). CCE or Customer Competitive Evaluation is one step in the HOQ process that involves comparing the product being developed to a similar product on the market to identify areas where the product is competitive and areas where it is not. The goal is to understand how the product being developed compares to similar products in terms of the features and attributes that are important to customers.

The first table shows the Customer's Competitive Evaluation of the proposed design.

Table 4.13 Customer Competitive Evaluation of Proposed Design

No.	Criteria	Score					Total
		1	2	3	4	5	
1	Process time			5	15		20
2	Safety				4	16	20
3	Durability			7	11	2	20
4	Precision			15	5		20
5	Easy to use			3	16	1	20
6	Customization		1	2	17		20
7	Affordability		11	5	4		20
8	Portability	17	3				20

Below is the Customer Competitive Evaluation of bamboo splitters in the market.

Table 4.14 Customer Competitive Evaluation of Bamboo Splitter

No.	Criteria	Score					Total
		1	2	3	4	5	
1	Process time			5	15		20
2	Safety		1	18	1		20

3	Durability		7	13		20
4	Precision		15	5		20
5	Easy to use		2	18		20
6	Customization		1	18	1	20
7	Affordability	2	3	15		20
8	Portability	18	2	0	0	20

The table below shows the Customer Competitive Evaluation of the bamboo splitter machine from Sonkusre et.al.,2013.

Table 4.15 Customer Competitive Evaluation of Bamboo Splitter from Sonkusre et.al.,2013

No.	Criteria	Score					Total
		1	2	3	4	5	
1	Process time		2	16	2		20
2	Safety		4	14	2		20
3	Durability		3	15	2		20
4	Precision			15	5		20
5	Easy to use			13	7		20
6	Customization	1	14	3	2		20
7	Affordability		1	3	15	1	20
8	Portability	17	3				20

The table below shows the Customer Competitive Evaluation of the bamboo splitter machine from Sutanto et.al.,2015.

Table 4.16 Customer Competitive Evaluation of Bamboo Splitter from Sutanto et.al.,2015

No.	Criteria	Score					Total
		1	2	3	4	5	
1	Process time	2	16	2			20
2	Safety		5	10	3	2	20
3	Durability		17	3			20
4	Precision	1	15	4			20
5	Easy to use	15	5				20
6	Customization	16	4				20
7	Affordability			2	3	15	20
8	Portability				18	2	20

Below is the summary of the Customer Competitive Evaluation of all products.

Table 4.17 Summary of CCE

No.	Customer needs	Proposed design	Machine in market	Sonkusre et.al.,2013	Sutanto et.al.,2015
1	Process time	3,75	3,8	3	2
2	Safety	4,8	2,85	2,9	3,1
3	Durability	3,75	2,1	2,95	2,15
4	Precision	3,25	3,05	3,25	2,15
5	Easy to use	3,9	3,9	3,35	1,25
6	Customization	3,8	3,05	2,3	1,2
7	Affordability	2,65	3,9	3,8	4,65
8	Portability	1,4	1,2	1,15	4,1

If we round the value, it will become.

Table 4.18 Rounded CCE

No.	Customer needs	Proposed design	Machine in market	Sonkusre et.al.,2013	Sutanto et.al.,2015
1	Process time	4	4	3	2
2	Safety	5	3	3	3
3	Durability	4	2	3	2
4	Precision	3	3	3	2
5	Easy to use	4	4	3	1
6	Customization	4	3	2	1
7	Affordability	3	4	4	5
8	Portability	1	1	1	4

4.2.9 Determining Goal, Sales Point, Improvement ratio, Row weight, and Action

a) Goal

The goal is the target of the satisfaction value to be achieved for the product will be developed. Determining the value of consumer satisfaction is done by using a scale [1-5] for each consumer need in the product being developed. The goal rating scale is shown in the following table Below is the scale of Goal. (Cohen, 1995)

Table 4.19 Goal scale

Scale	Description
1	very unsatisfactory
2	not satisfactory
3	decent

4	satisfying
5	very satisfying

The goal values for each customer's needs can be seen in the table below:

Table Goal values for each Customer's needs

Table 4.20 Goal value

Customer needs	goal
Process time	3,4
Safety	3,2
Durability	3
Precision	2,8
Easy to use	3,2
Customization	2,8
Affordability	4
Portability	1,6

b) Sales Point

Sales Point is an attribute that defines the product have a high sale point, especially for selling the product. Sales Point is conducted to know the value of the product based on the action of improvement of the product in customer requirement which will be resulting in competitive power in the product advertising. To define the Sales Point value is use [1; 1,2 and 1,5] for each customer needs parameter of the product that is currently developed. The table below is the sales point scale.

Table 4.21 Sales points scale

Sales Point	Description
1	No Sales Point
1,2	Decent Sales Point
1,5	Strong Sales Point

The value of sales points for each customer's needs can be seen in the table below:

Table 4.22 Sales points for each customer needs

Customer needs	Sales Point
Process time	1,2
Safety	1,5
Durability	1,2

Precision	1
Easy to use	1,2
Customization	1,2
Affordability	1
Portability	1

c) Improvement Ratio

The improvement Ratio is used to show how drastically the changes or the improvement that needs to do. The formula to get the Improvement Ratio is mentioned below:

$$\text{Improvement Ratio} = \frac{\text{Goal}}{\text{Current satisfaction performance}}$$

Improvement Ratio has its own scale, the scale can be seen in the table below:

Table 4.23 Improvement ratio scale

Improvement Ratio	Description
<1	No Changes
1-1,5	Moderate Changes
>1,5	High Changes

The improvement Ratio calculation for each Customer's Needs can be seen in the table below:

Table 4.24 IR on our design

Customer needs	Improvement Ration Proposed Design
Process time	0,8
Safety	0,7
Durability	0,7
Precision	0,9
Easy to use	0,8
Customization	0,6
Affordability	1,3
Portability	1,8

d) Row Weight

Row Weight is used to show the improvement of the Customers' Needs attribute. The formula to get the Row Weight value is mentioned below:

$$\text{Row Weight} = \text{Importance Rating} \times \text{Improvement Ratio} \times \text{Sales Point}$$

Based on the formulation above, we can get.

Table 4.25 Row Weight of the proposed design

Customer needs	Importance Rating	Sales point	Improvement Ratio	Row Weight
Process time	4,8	1,2	0,8	4,7
Safety	4,7	1,5	0,7	4,9
Durability	4,7	1,2	0,7	3,9
Precision	4,8	1	0,9	4,4
Easy to use	4,6	1	0,8	3,5
Customization	4,5	1,2	0,6	3,4
Affordability	4,6	1	1,3	6,1
Portability	1,9	1	1,8	3,3

e) Action

Actions on the development of new products/services are determined through an analysis strategy in the House of Quality. These strategies are divided into several categories, which will be mentioned below:

1. A category: Improve product quality.
2. B category: Maintain product quality and continuously innovate products.
3. C category: Maintain product quality.

Below is the action table based on the description above:

Table 4.26 Action table

Customer needs	Row Weight	Action
Process time	4,7	B
Safety	4,9	B
Durability	3,9	B
Precision	4,4	B
Easy to use	3,5	C
Customization	3,4	C
Affordability	6,1	A
Portability	3,3	C

4.2.10 House of Quality Phase 1

The first phase of the Quality Function Deployment method is known as the house 1, Phase 1, or Product planning matrix. This phase is the most comprehensive phase of the product development process because it is contained What's (Customer Requirement), How's (Technical Requirements), Relationship matrix between What's and How's, CCE (Customer Competitive Evaluation), and Importance Rating. HOQ contains information such as customer needs, technical characteristics, targets, and comparison of competitor products. All of that information is needed to help the researcher to determine what is required, and what is the important things in developing a new product, so that the product that is developed will have advantages over previous products. The matrix itself can be seen in the picture below.

House of Quality below is the HOQ of the current proposed design of the bamboo splitter machine.

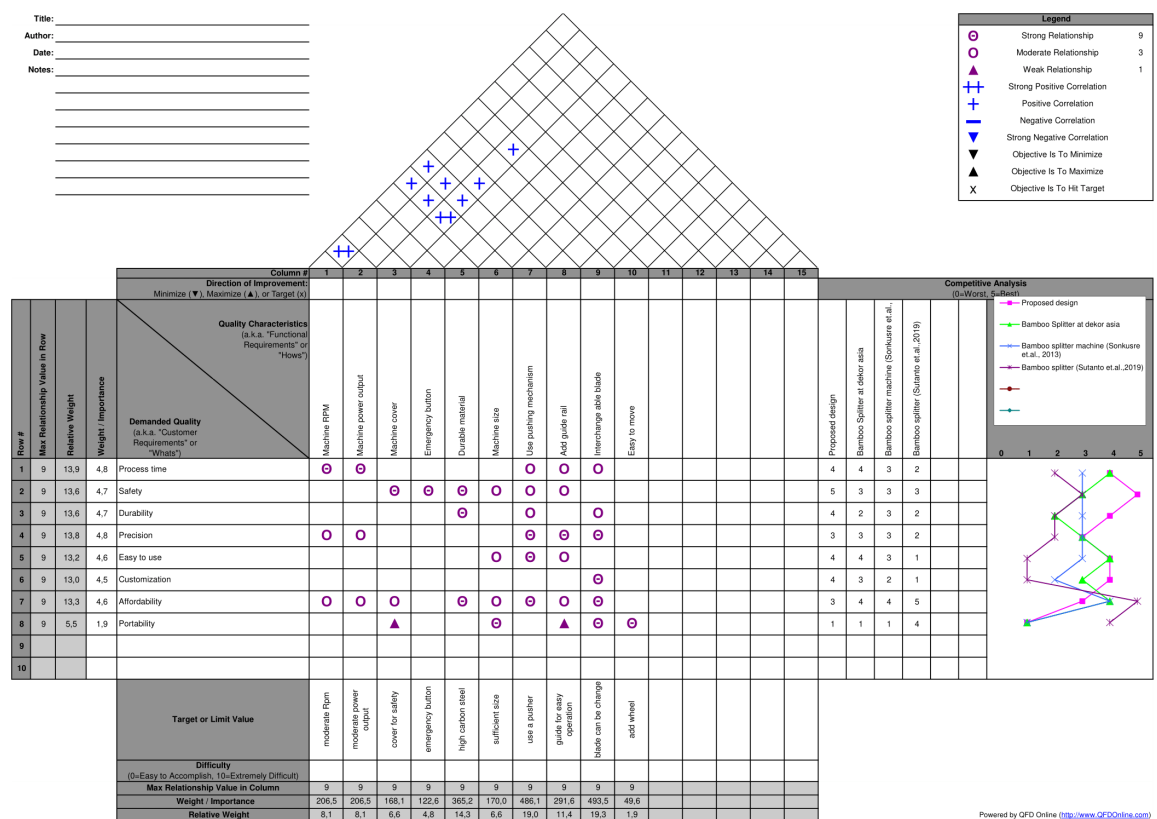


Figure 0.6 House of Quality of the proposed design

4.2.11 Part Deployment Matrix

The Part Deployment Matrix is a tool used in Quality Function Deployment (QFD) to analyze how various parts of a product or service are affected by customer requirements. It is a matrix that cross-references each customer requirement with each part of the product or service, indicating how important each requirement is for each part.

These steps also help identify which parts of the product or services are most critical to customer satisfaction and which requirements are most important for each part. This information can then be used to prioritize design and development efforts.

By using the Part Deployment Matrix, design teams can ensure that customer requirements are properly integrated into the design of each part of the product or service resulting in higher customer satisfaction.

In the process of determining the critical part, a concept analysis needs to be done in order to get the critical parts. One of the methods to identify critical parts is to use Fault Tree Analysis. By employing it, the researcher can gather information about component-component that are predicted to cause target divergence with the Technical Requirement. But before we determine the critical parts, we need to create a concept analysis. In concept analysis, there are criteria such as formulation as well as the details of this bamboo splitter machine that will be further developed. Below are the consumer requirements for bamboo splitter machines.

Consumer Requirements Based on Phase 1

Based on the HOQ (House of Quality) phase 1, the technical requirement needed for this product is:

- Process Time
- Safety
- Durability
- Precision
- Easy to Use
- Customization
- Affordability
- Portability

4.2.12 Fault Tree Analysis

Fault tree analysis (FTA) is a tool used in Quality Function Deployment (QFD) to identify the causes of failures or problems in a system or product. It is a graphical method that uses logic diagrams to identify the combinations of events and conditions that could lead to the failure of the system or product.

Table 4.27 Fault tree analysis table

No	Technical Requirement	Component Analysis
1	Machine Rpm	Rpm 750-3000 Electric Generator
2	Machine Power Output	3Kw-5,5Kw Power Output Electric Generator
3	Machine Cover	Hollow Beam Aluminium Sleeve
4	Emergency Button	Emergency Button
5	Durable Material	High Carbon Steel
6	Machine Size	Use Local Height Measurement
7	Use Pushing Mechanism	Improved Pusher Design
8	Add Guiding Rail	High Carbon Steel
9	Interchangeable Blade	High Carbon Steel
10	Easy to Move	Add wheel

4.2.13 House of Quality Phase 2

After the 6 components of Characteristic is identified before, the data are inputted to the Part Deployment matrix, and determine its relationship. The matrix can be seen below.

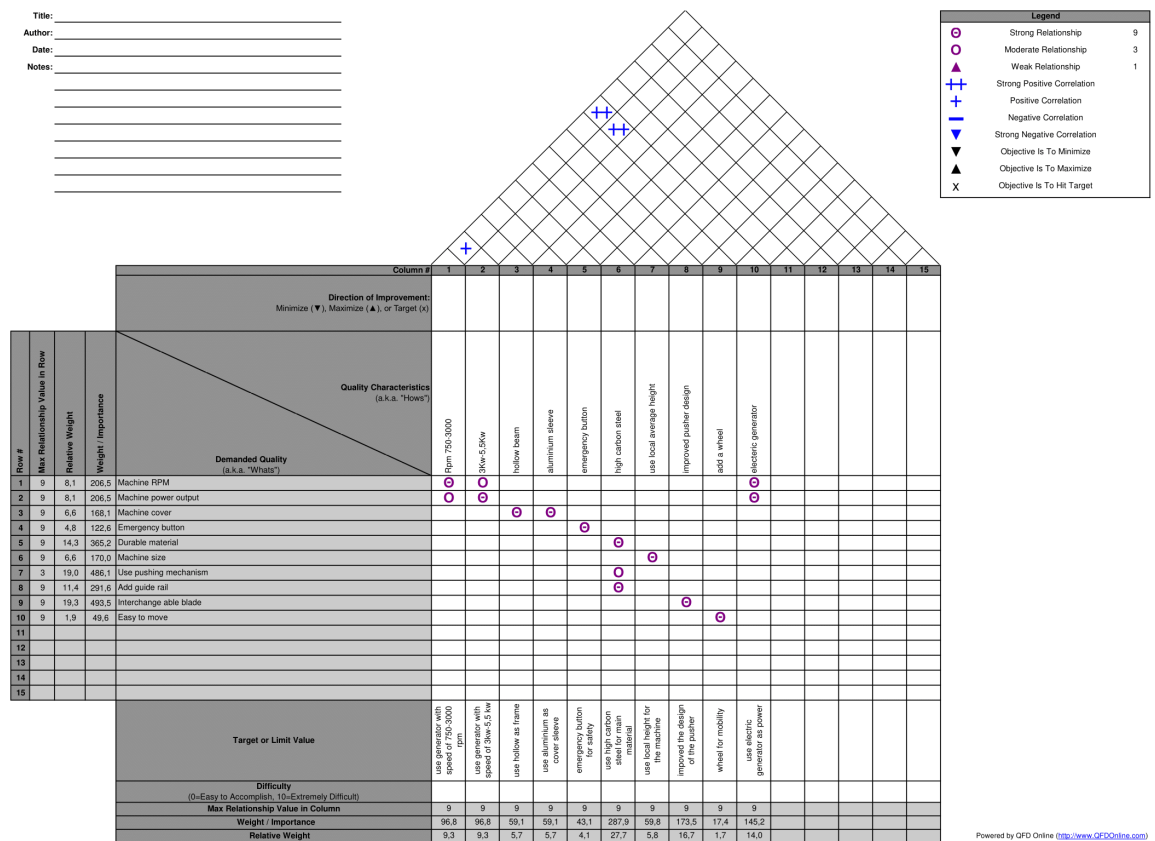
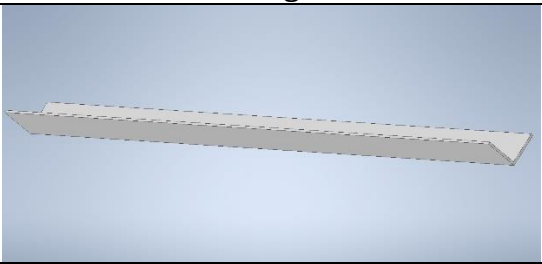


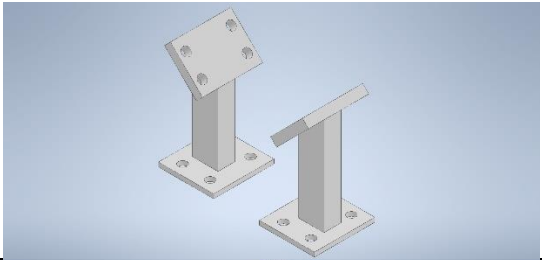
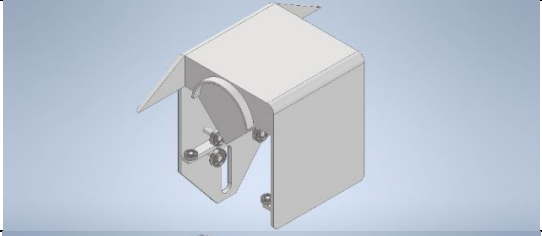
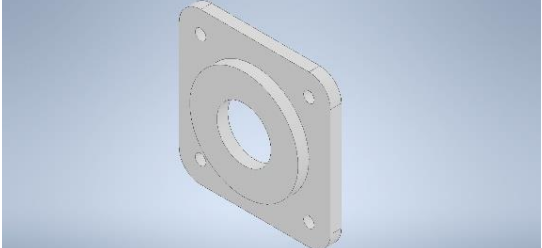
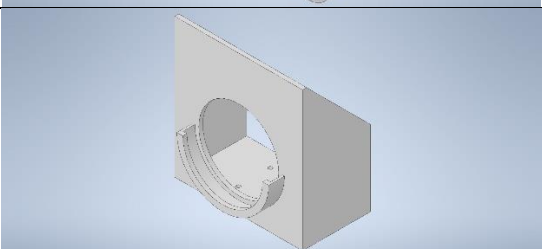
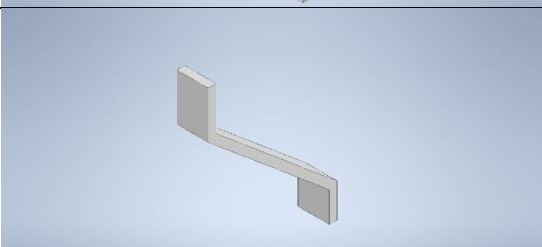
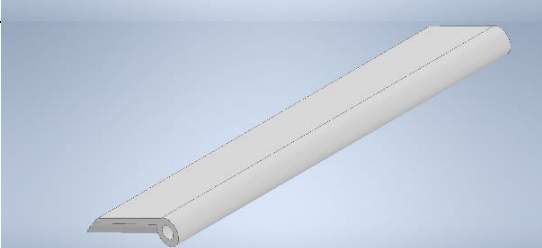
Figure 0.7 Part deployment matrix

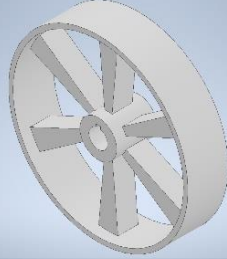
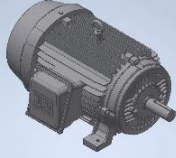
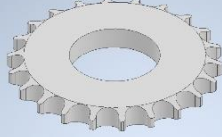
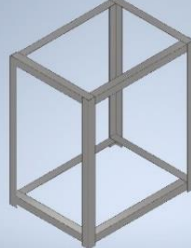
4.3 Virtual Design

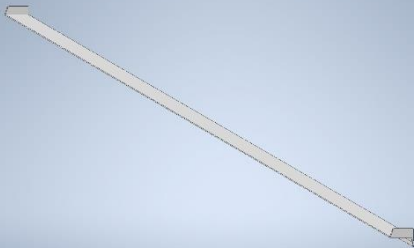
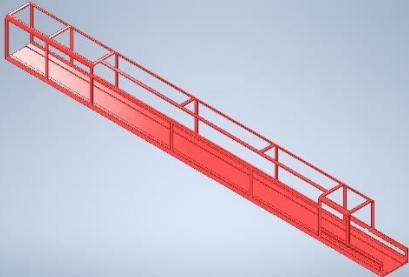
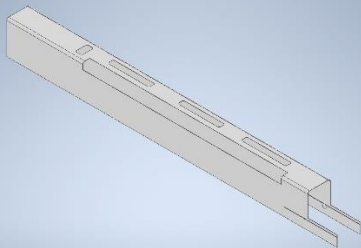
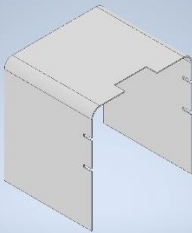
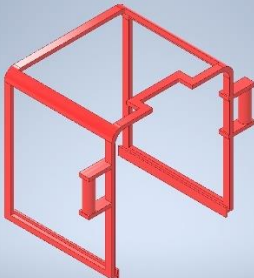
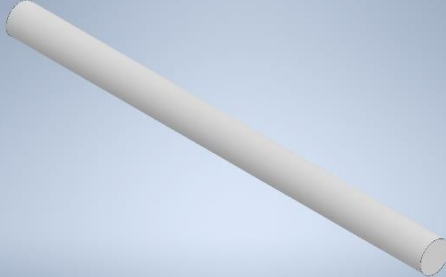
Virtual design is created to give visual interpretation to the consumer of the developed product which is the Bamboo Splitter Machine that is based on the customer requirement. Below is the visual design of the Bamboo Splitter Machine based on the analysis above.

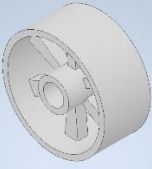
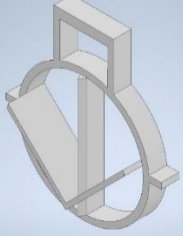
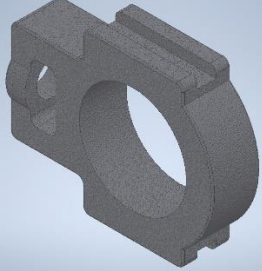
Table 4.28 List of used parts

No.	Part	Quantity	Design
1	Bamboo Guide	1	

2	Bamboo Guide Stand	18	
3	Bamboo Pusher	1	
4	Bearing Cover	2	
5	Blade Base	1	
6	Bracket	1	
7	Bridge	3	
8	Chain with Driver	1	

9	Drive Wheel	1	
10	Electric Motor	1	
11	Emergency Button	1	
12	Gear	2	
13	I Beam AS 3679 (5000mm)	1	
14	Legs	2	

15	Loader	1	
16	Machine Cover Frame	1	
17	Machine Cover Sleeve	1	
18	Moving Cover Frame	1	
19	Moving Cover Sleeve	1	
20	Shaft	1	

21	Short Shaft	1	
22	Small Drive Wheel	1	
22	Splitter Blade	1	
22	T207	2	

Above is the table of the parts that are used in this machine, there are 22 different parts excluding bolt and ball bearing. Many of the parts are commonly available in the market so they can be fixed or changed easily.

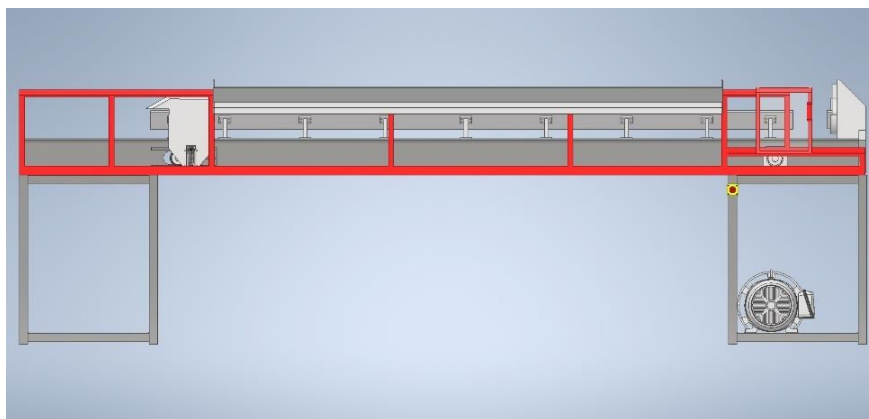


Figure 0.8 Bamboo Splitter Machine from the left side

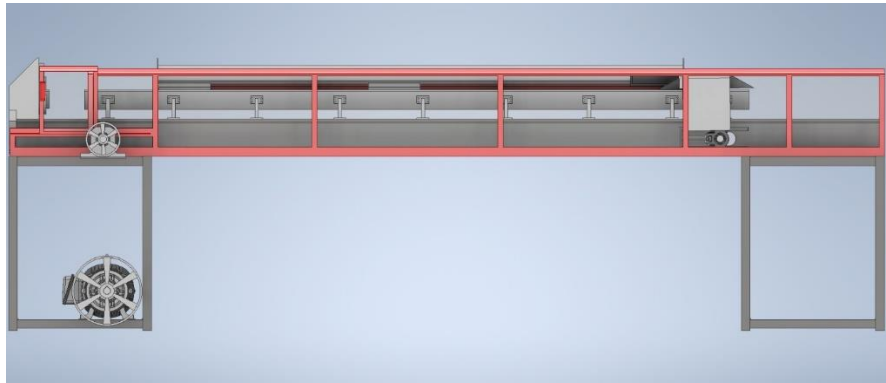


Figure 0.9 Bamboo splitter machine from the right side

The bamboo splitter machine is designed based on the bamboo splitter machine that is commonly available on the market. The difference between this machine and the machine that is commonly available on the market are:

A. Safety Metal Cover

This machine uses a metal cover as a safety feature with 10 mm frame thickness, and 3 mm sleeve thickness. The cover is span over 5000 mm or 5 meters, 345,997 mm in width, and 503 mm in height.

Also, there is a moving cover right in front of Blade Base, the material is the same as the metal cover with 10 mm frame thickness and 3 mm sleeve thickness. The moving cover length is 328 mm, 393.828 mm in height, and 375.997 mm in width. It is also having a handle to move the cover easily.

B. Bamboo Pusher

Since this machine is use pushed mechanism, the bamboo pusher for this machine is designed specifically for this machine.

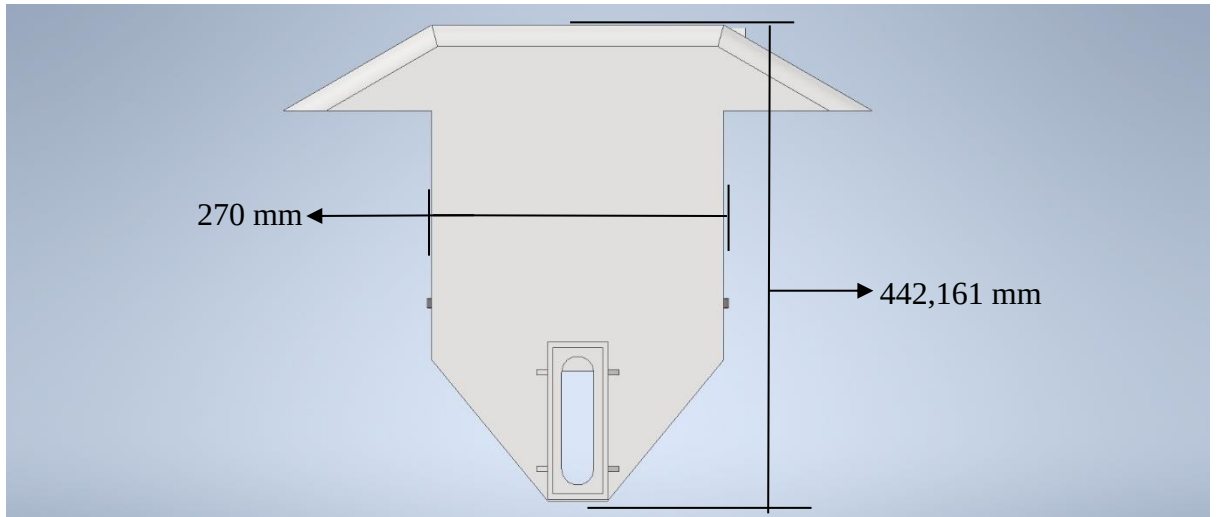


Figure 0.10 Bamboo Pusher side view

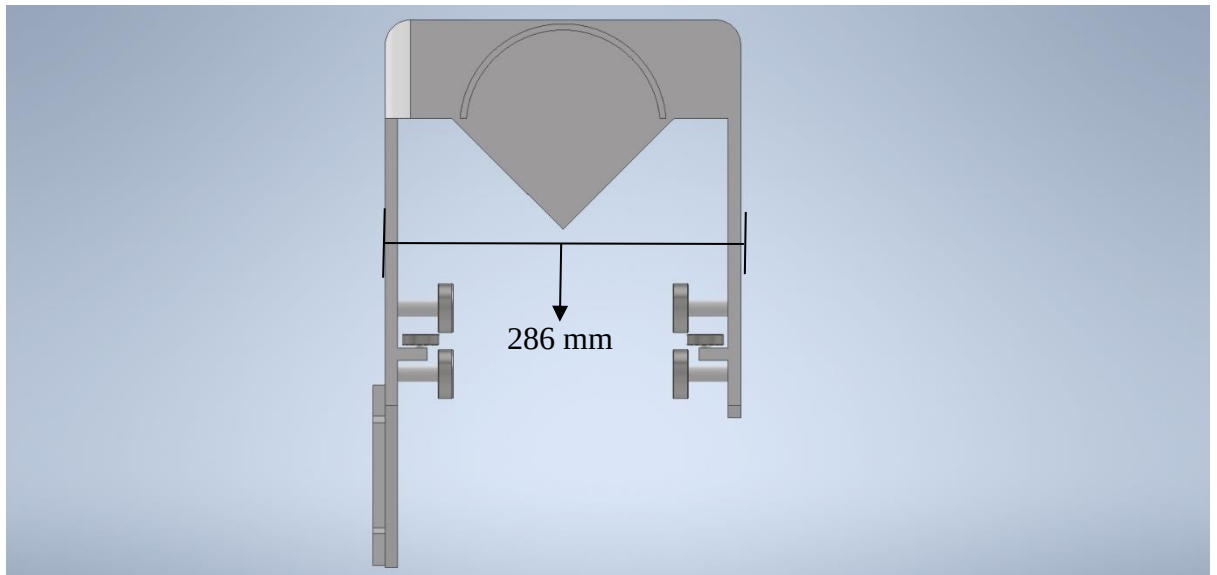


Figure 0.11 Bamboo Pusher front view

Above is the bamboo pusher part figure from many angles, it consists of the pusher itself, 8 medium bearings, and 4 small bearings which function as a guide for the pusher. The dimension for the pusher is 442.161 mm in height, 270 mm in length, and 286 mm in width.

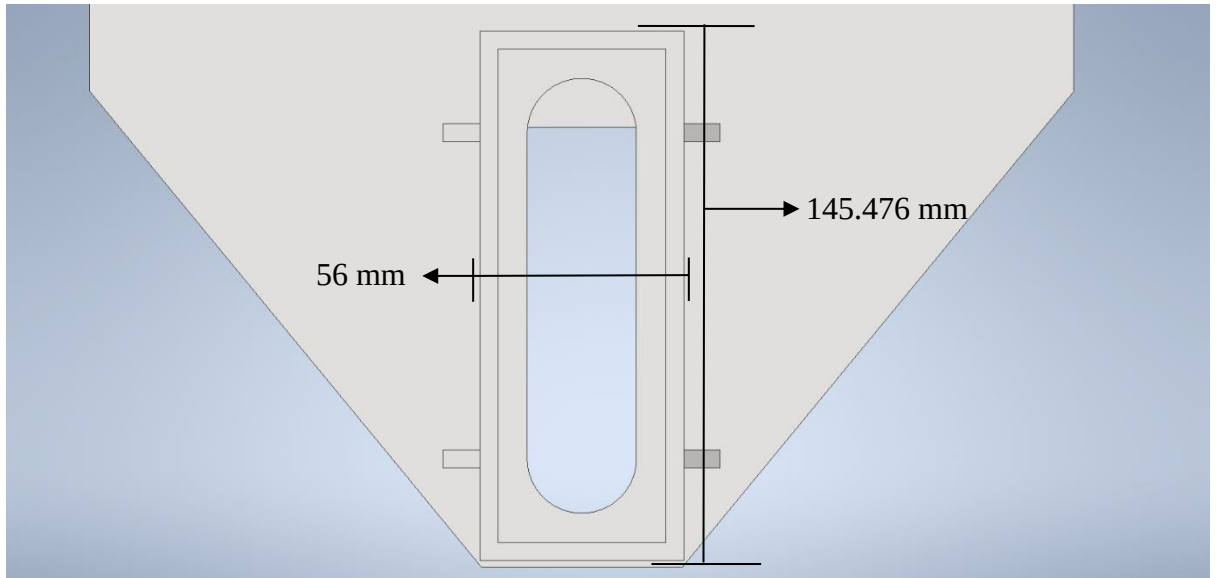


Figure 0.12 Bamboo pusher zoomed

As we can see above, above is a slot for connecting the pusher and the chain, which the pusher can move to push the bamboo. The design is improved from the commonly available machine, in this machine the slots are added as a barrier for limiting the moving of the bearing, so the connected pin doesn't make a contact and damaged the Bamboo Pusher. The barrier itself is 5 mm thick and 10 mm depth.

C. Improved mechanism

The mechanism to move the pusher in this machine is nearly the same as the bamboo splitter machine that is commonly available on the market. The mechanism of a common machine is illustrated below.



Figure 0.13 Bamboo pusher current mechanism

Above is the common mechanism used in bamboo splitter machines in the market. Unfortunately, disadvantages also existed in using this mechanism, the pin that connects the chain with the pusher degraded over time as seen in the picture above, both the pin and the pusher are damaged, and the pin has the potential to break because of the high impact force of the machine. Below is the mechanism used in the proposed machine.

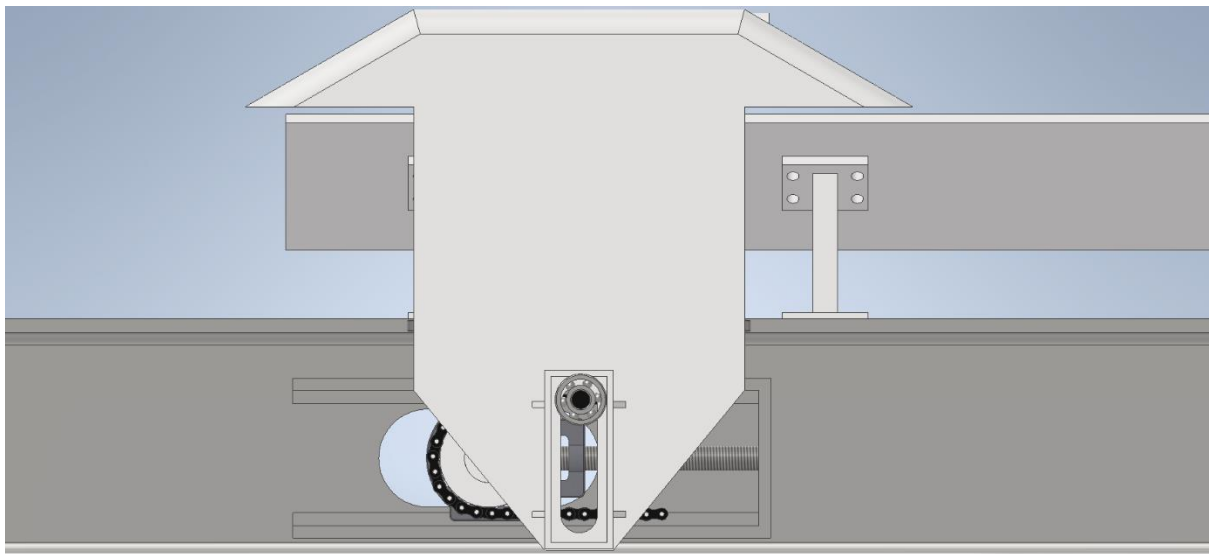


Figure 0.14 Proposed bamboo pusher mechanism

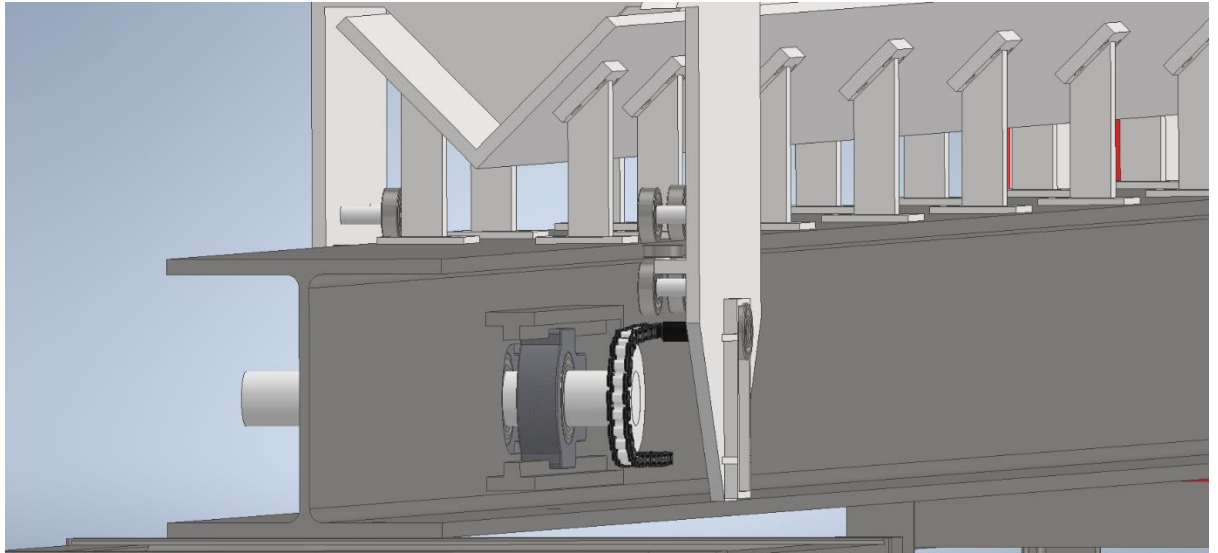


Figure 0.15 Proposed bamboo pusher mechanism from side part

As we can see in the visual design above, the mechanism is nearly the same with several changes. The pin is still used but it doesn't have direct contact with the pusher part, instead at the end of the pinball bearing is added as a contact point with the pusher part. With this mechanism, the pusher part will not be damaged as bad as the previous mechanism.

D. Blade Base and Splitter Base

Because the mechanism used in this machine is pushed mechanism, we can use the passive blade and make the base for the blade.

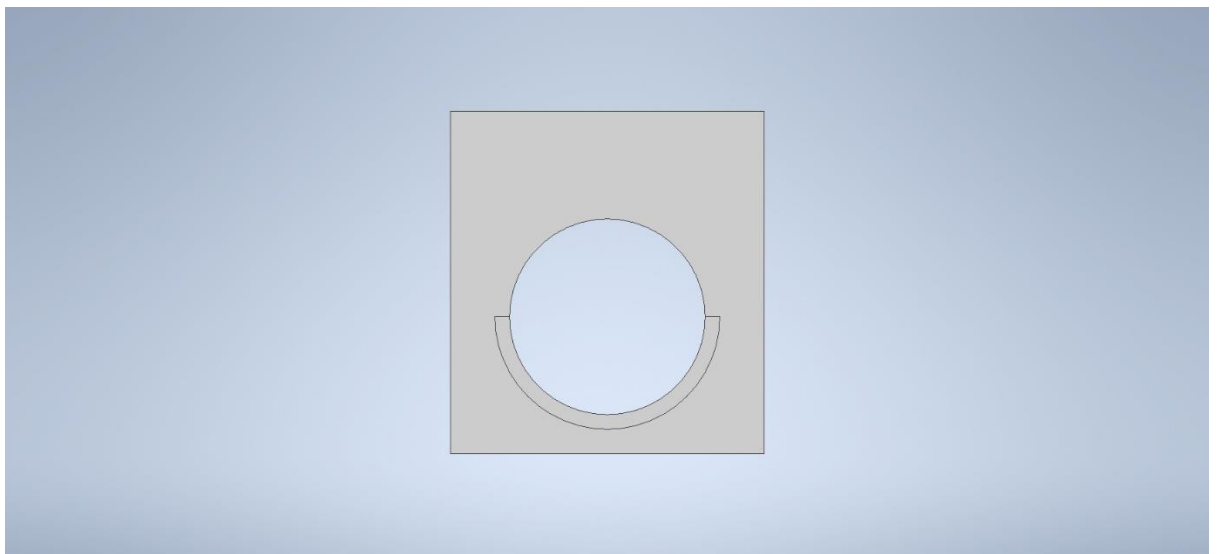


Figure 0.16 Blade base front view

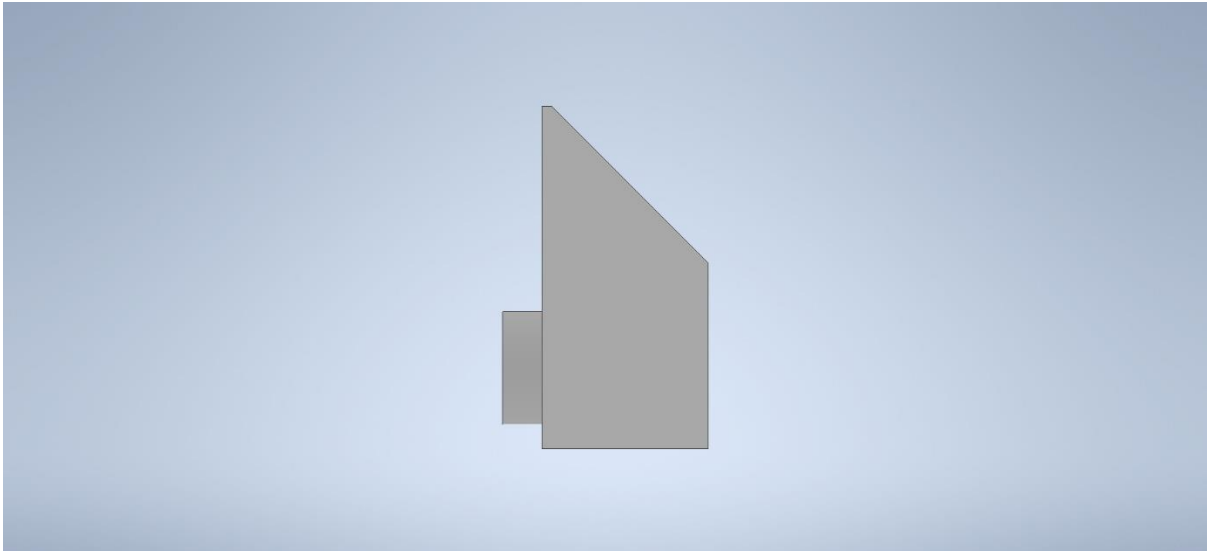


Figure 0.17 Blade base side view

Above is the design of the base for the blade, the design is adapted from a similar machine that is commonly available on the market. The dimension is 320 mm width, 350 mm height, and 170 mm length. The diameter of the main thru hole is 200 mm, and the height is 140 mm from the bottom.

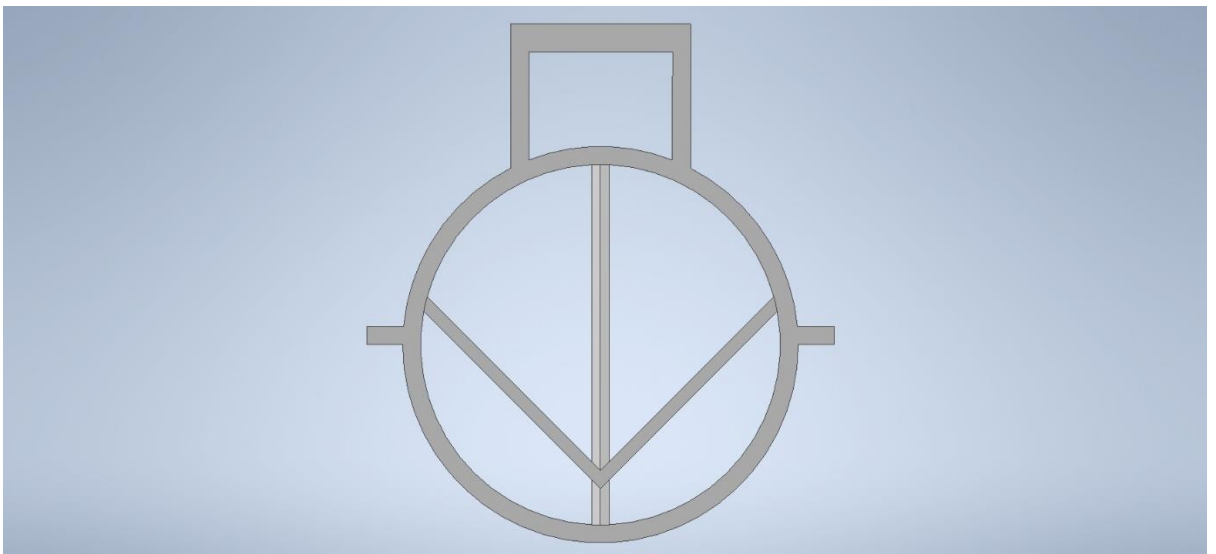


Figure 0.18 Splitting blade front view

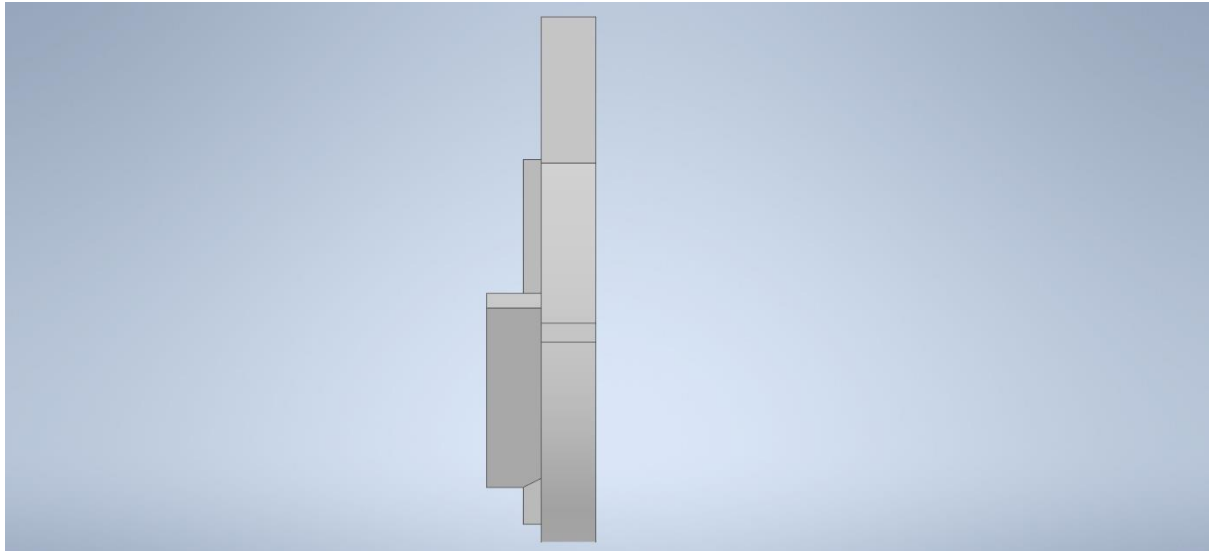


Figure 0.19 Splitting blade side view

Above is a picture of the blade itself, there are 2 types of blade splitter (half) blade and splitter (quarter) blade, the main difference is the quantity of the blade and the output of the bamboo when it is used. The inner diameter of the blade is 200 mm, 220 mm for the outer diameter, and 30 mm width. The blade also has a handle so they can be exchanged easily.

E. Bamboo Guide

A bamboo guide is available, so the operator doesn't need to hold the bamboo until it is pushed by the pusher. It is placed right in the center and aligned with the blade, with the help of the guide stand.

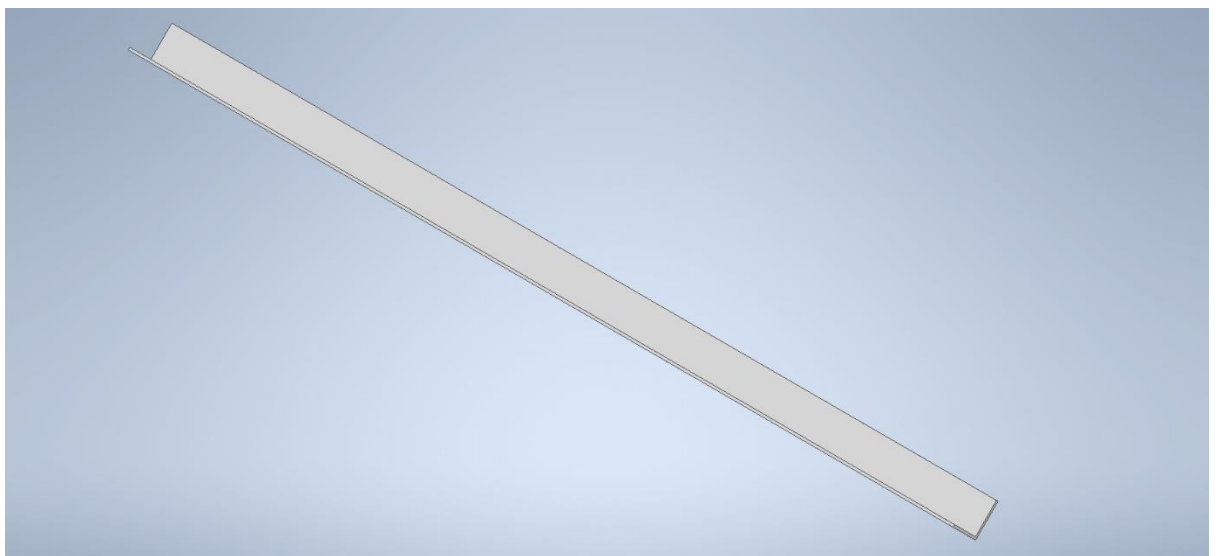


Figure 0.20 Bamboo bridge

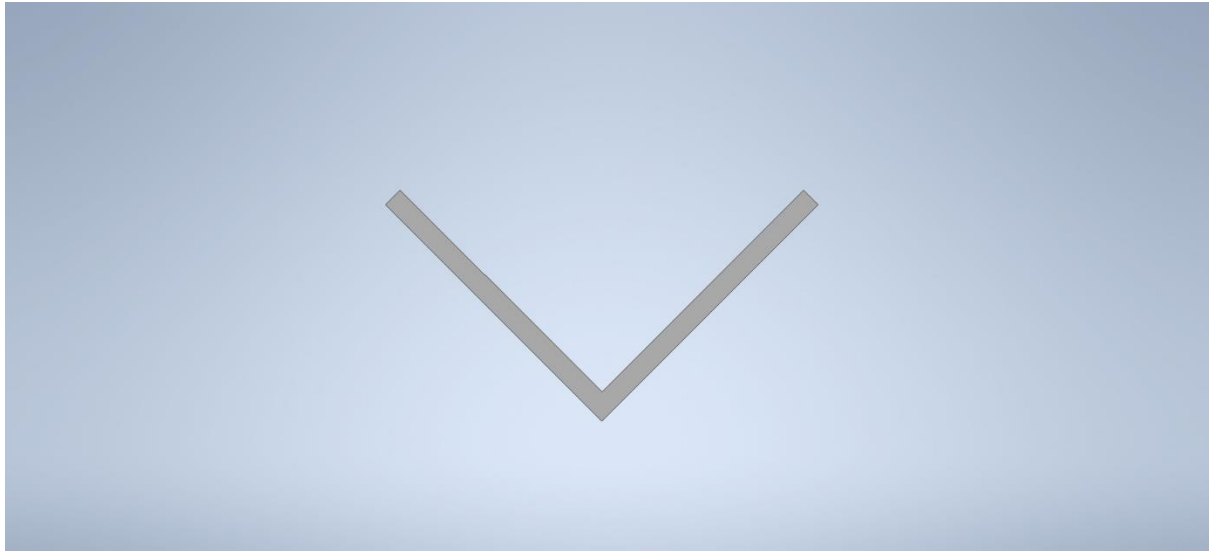


Figure 0.21 Bamboo bridge front view

The dimension of these parts is 3800 mm or 3.8 meters, and 10 mm thick. Below is the picture of the stand for this part.

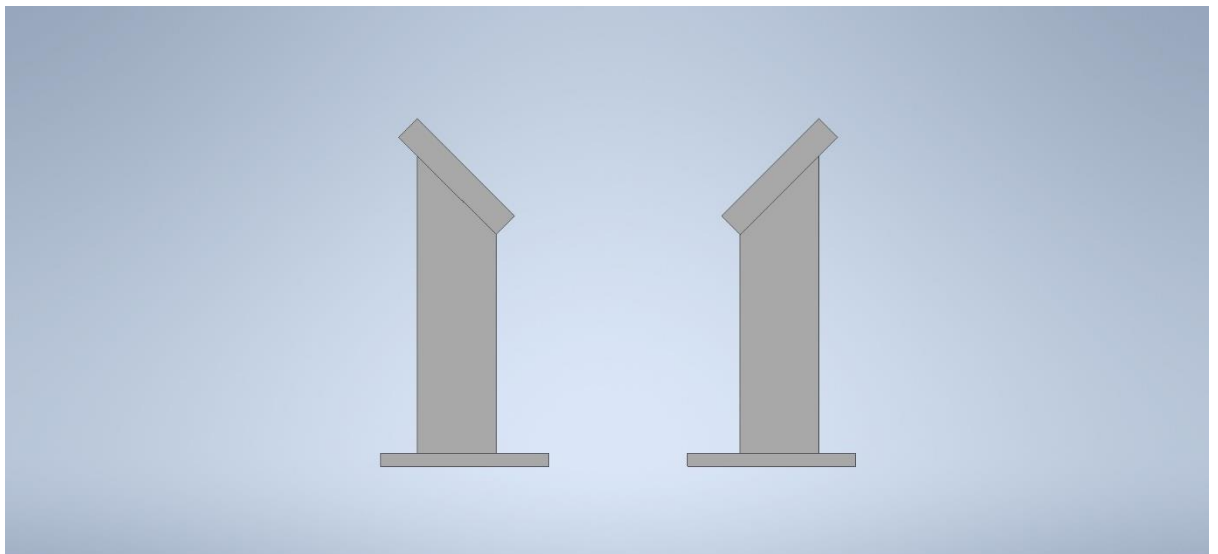


Figure 0.22 Bamboo bridge stand front view

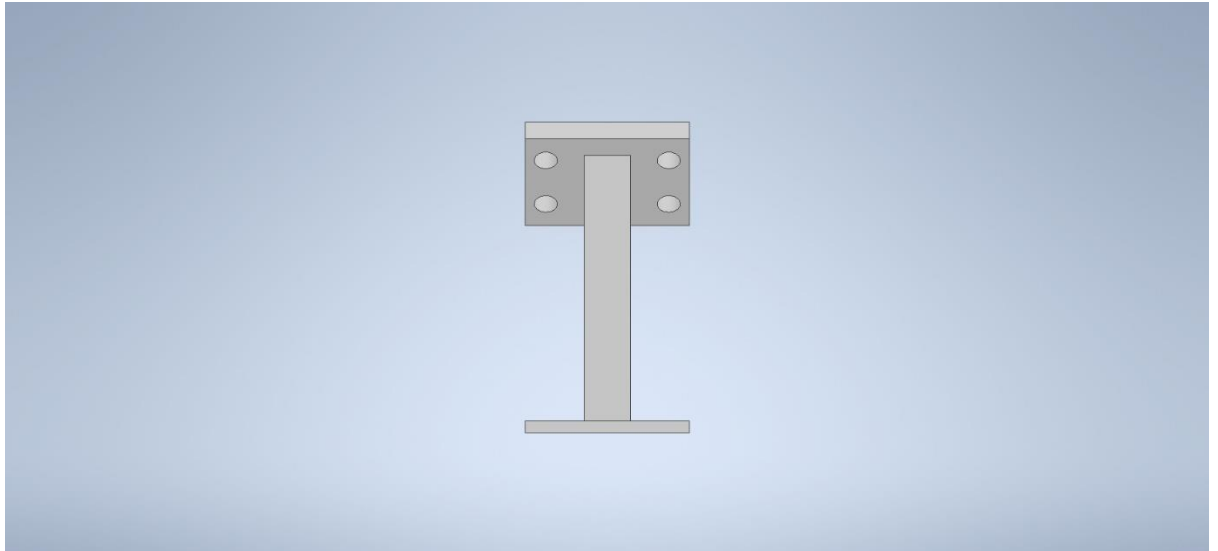


Figure 0.23 Bamboo bridge stand side view

This stand helps the bamboo guide to stay in its position and stay aligned with the blade.

F. Loader and Bridge

This machine is also equipped with a loader bay, it works as a platform to place the bamboo before gets into the machine to be split. The loader is span over 3000 mm or 3 meters long and 5 mm thick with flaps on each end to keep the bamboo in.



Figure 0.24 Bamboo loader design

Above is the design of the loader, it will attach directly to the machine cover. To prevent bamboo gets in into the machine while the pusher is working, a stopper called “Bridge” is created to prevent it. Below is the visual design of the “Bridge”.

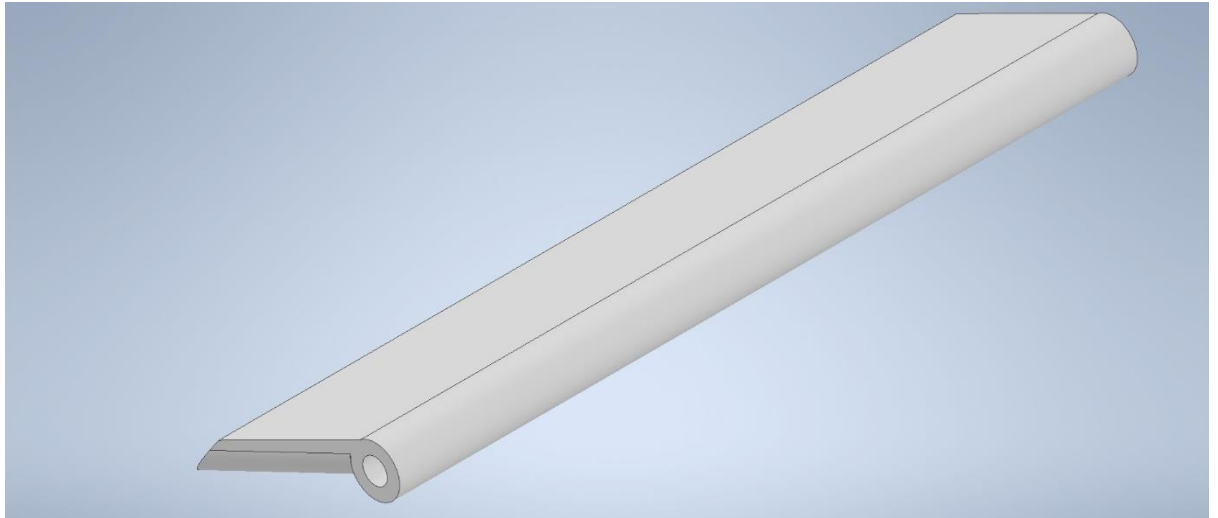


Figure 0.25 Bridge design

The bridge is there to help bamboo gets in into the machine from the loader part, it is also there to prevent bamboo gets in while the pusher is in a working position. It is 300 mm or 30 cm long. The bottom of each end is sloped so the pusher can lift it up easily and reduce the friction between the two parts. There will be 3 pieces of these parts in the machine.

G. “T207”

“T207” is a common part largely used in many types of machines, such as the commonly available bamboo splitter machine, this part is also used in this bamboo splitter machine. The only difference is how it is positioned.



Figure 0.26 “T207” position on a common machine

As we can see in the picture above, the position of “T207” is in the commonly available bamboo splitter machine. With this position, this part can break easily because of the positioning, with this position the force is pulling force, combined with the high impact at the end of the machine, this part can break in the area that will visualize below.



Figure 0.27 break point of “T207” part in the current machine



Figure 0.28 Damaged “T207” part

The picture above is the area where “T207” is broken because high pull force of the machine. Because of this issue, the positioning of “T207” in the proposed machine is rotated 180 degrees. Below is the visualization.

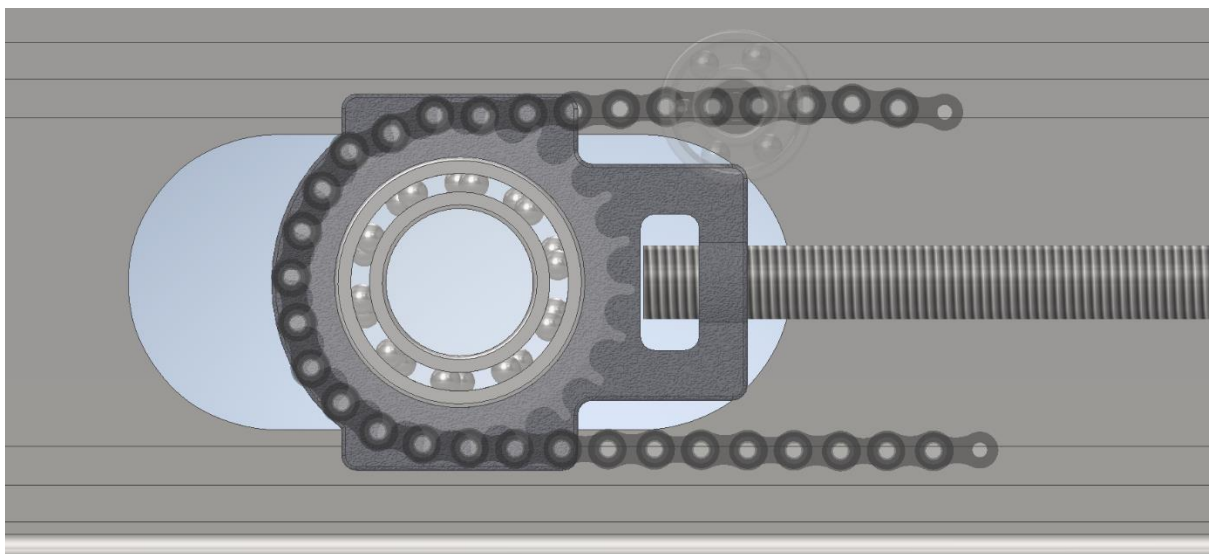


Figure 0.29 “T207” on the proposed machine

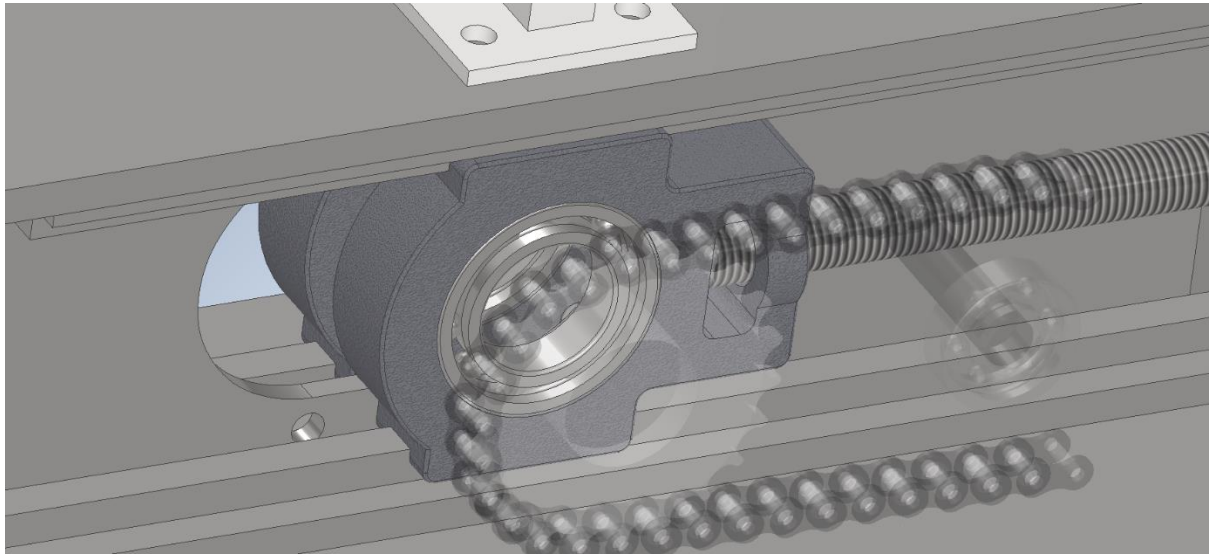


Figure 0.30 “T207” on the proposed machine

As we can see, the part is turned 180 degrees, to change the force from pull to pushing force. With this new position, this part is expected to live longer than using the previous position.

H. Electric Motor

An electric motor is used to drive this machine, it used electricity to power this motor. The motor can generate up to 3000 Rpm. A chain is used to transfer the power from the motor to the machine, as illustrated below.

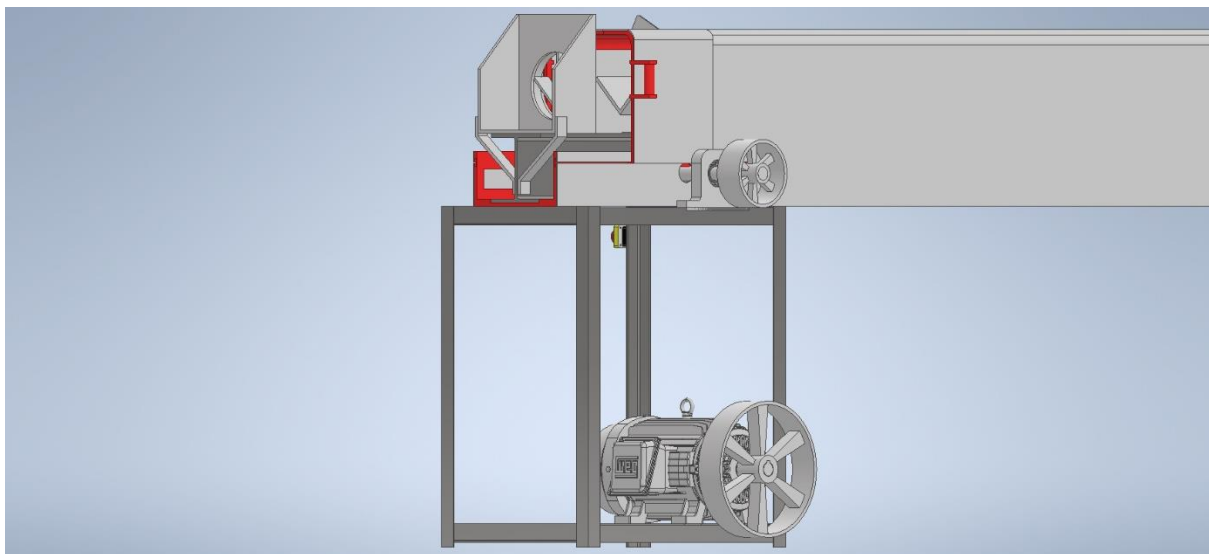


Figure 0.31 Electric motor

I. Emergency Stop

This machine is also equipped with an Emergency stop button to stop the operation immediately if there is any problem or issue within the machine that can both harm the operator and harm the machine itself.

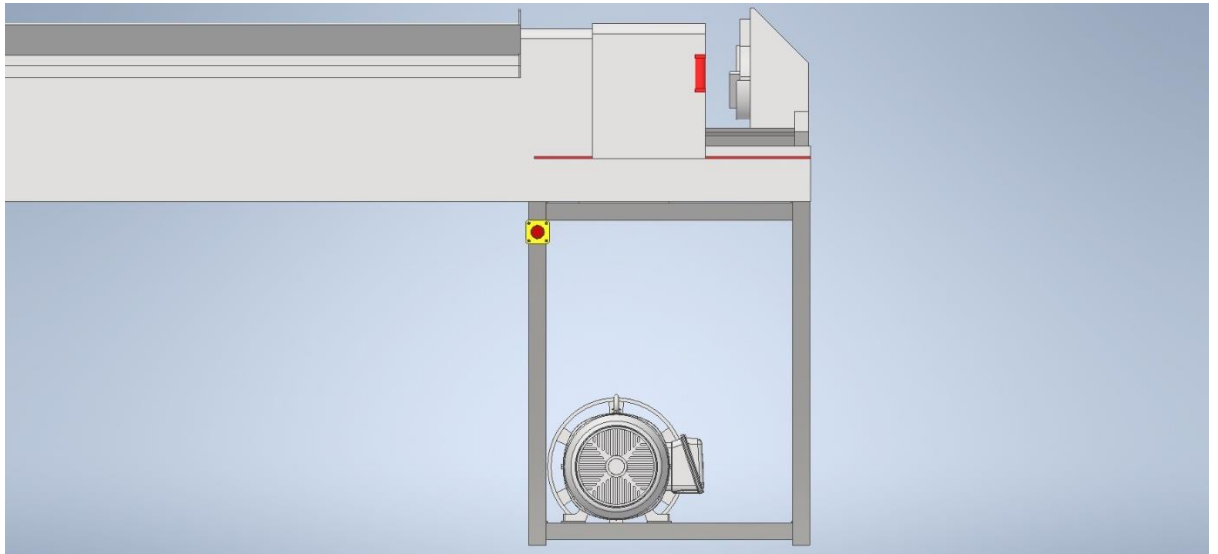


Figure 0.32 Emergency stop button

Below is another visual design illustration of this proposed machine.

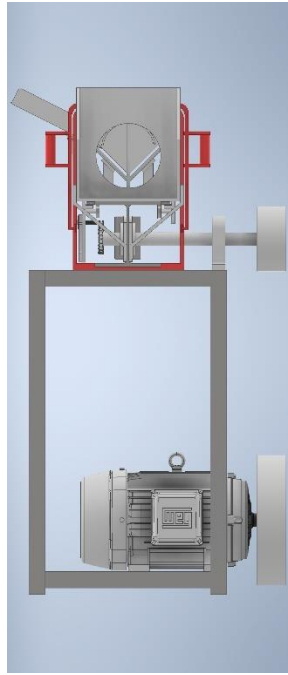


Figure 0.33 Bamboo splitter machine from front

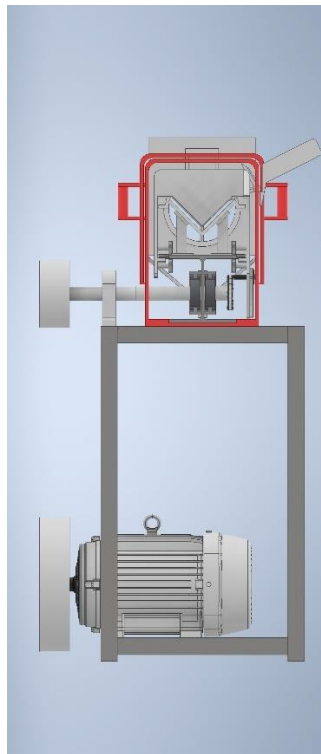


Figure 0.34 Bamboo splitter machine from below

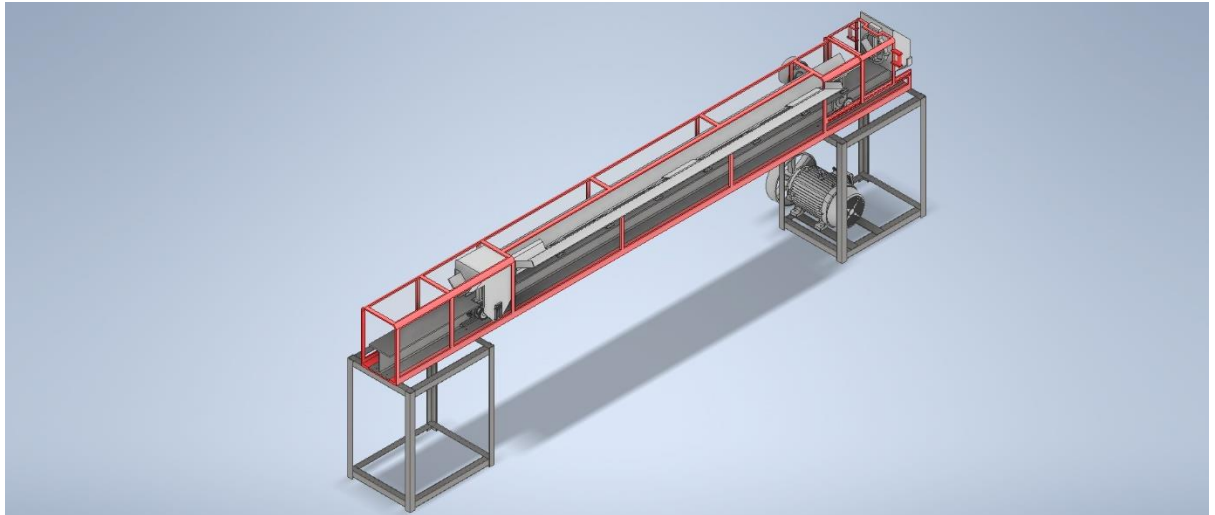


Figure 0.35 Bamboo splitter machine without cover from above 1

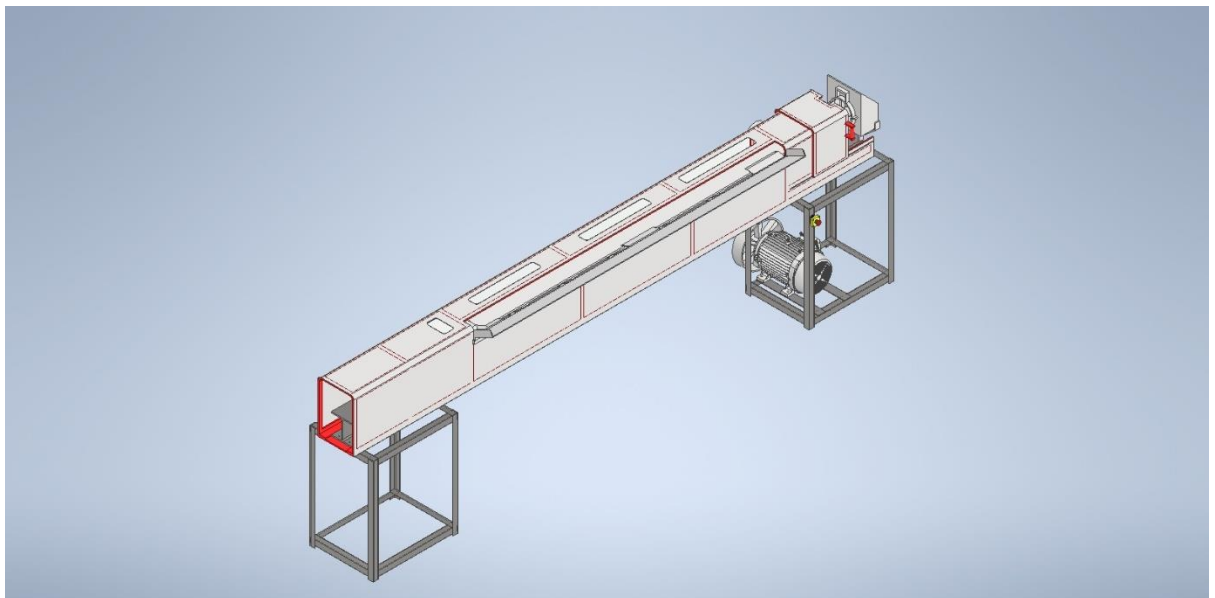


Figure 0.36 Bamboo splitter machine with cover from above 1

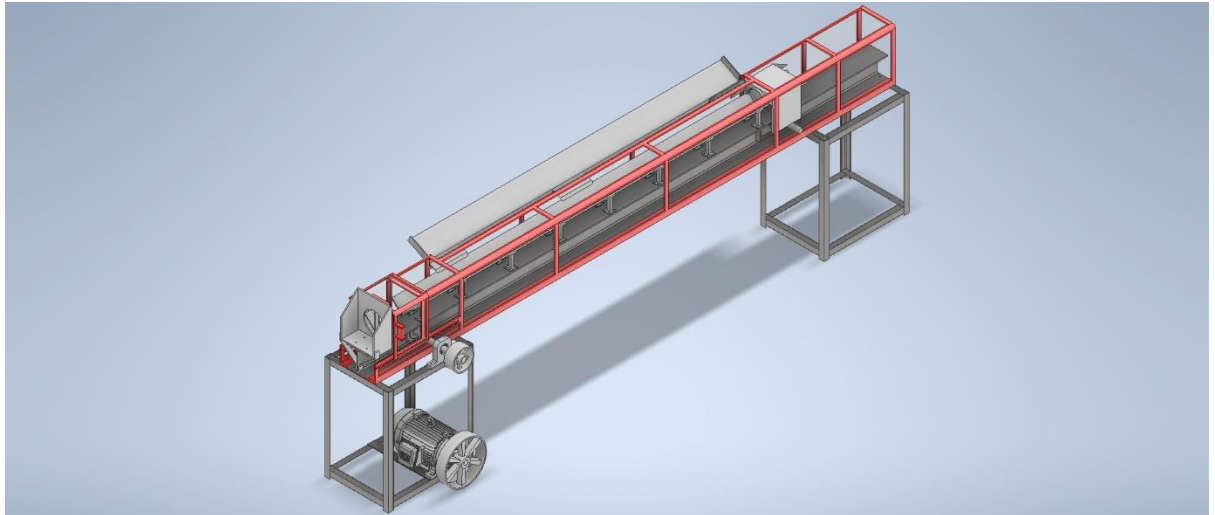


Figure 0.37 Bamboo splitter machine without cover from above 2

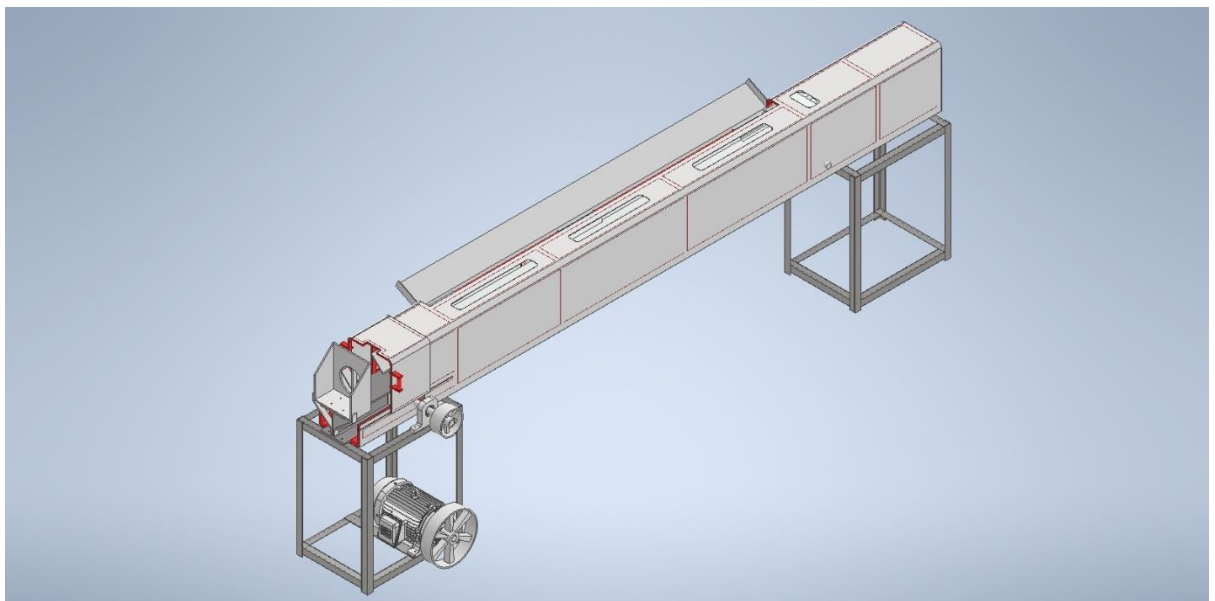


Figure 0.38 Bamboo splitter machine with cover from above 2

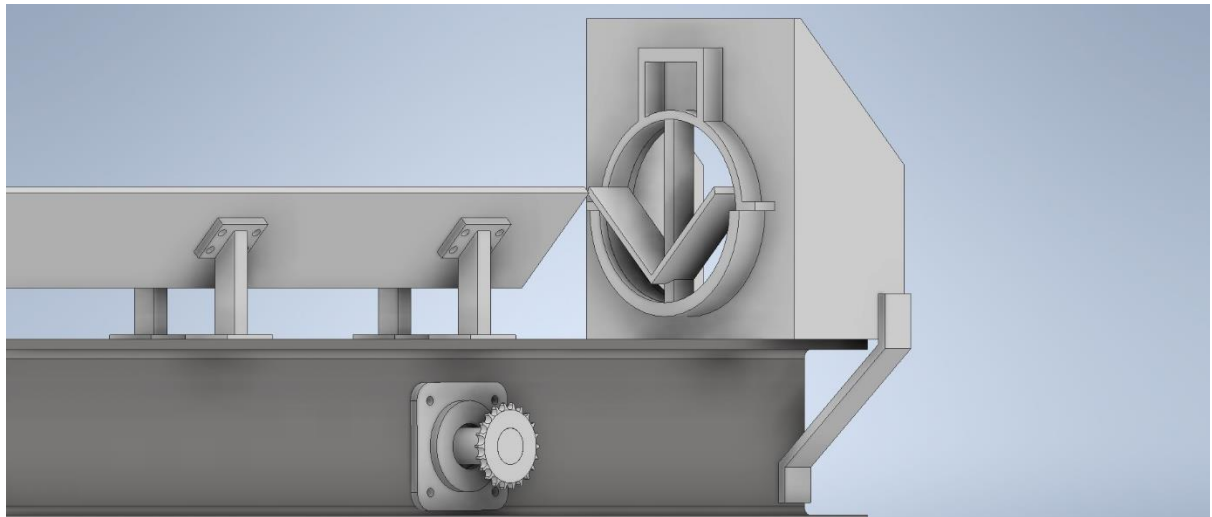


Figure 0.39 Blade base with splitter blade

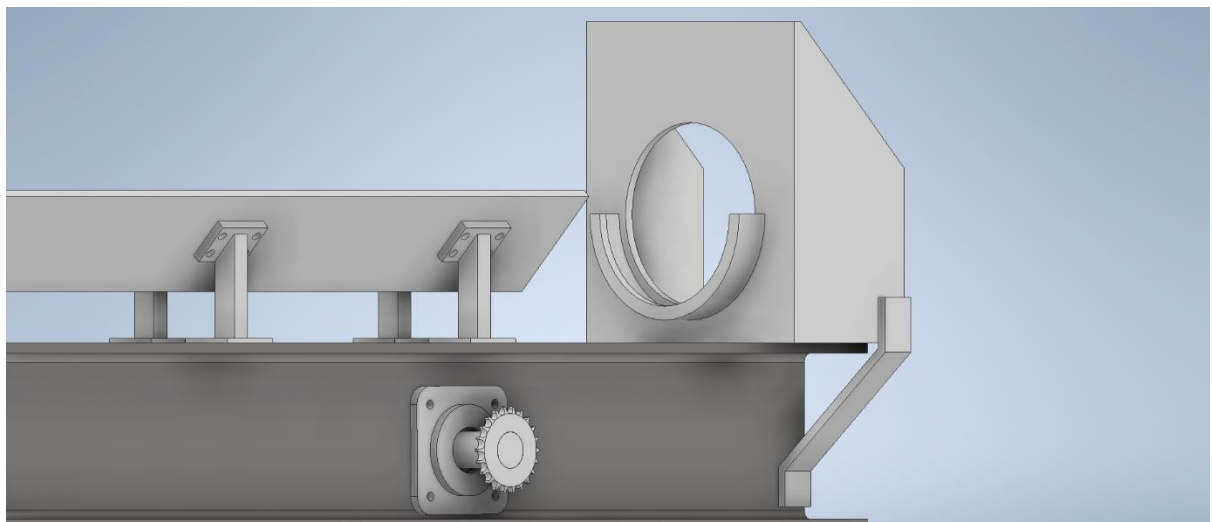


Figure 0.40 Blade base without splitter blade

After we generate the virtual design of the bamboo splitter machine, then we estimate the cost to produce the machine, this estimation price is based on the price researcher found in domestic and international markets, the price may be changed it can be lower or even higher depending on the current market situation, stock availability, distributor.

No	Part Name	Material type/name	Quantity	Price per item	Total Price
1	Bamboo Guide	5mm Steel	1074260,68 mm	Rp0,74	Rp789.581,60
2	Bamboo Guide Stand x18	5mm Steel	7521,52 mm	Rp0,74	Rp99.509,71
		Hollow Beam 30x20	1530 mm	Rp1,94	Rp53.549,99
3	Bamboo Pusher	5mm Steel	8778,59 mm	Rp0,74	Rp6.452,26

	10mm Steel	312805,09	mm	Rp2,40	Rp750.732,22
4	Bearing	6008	2 Pcs	Rp6.600,00	Rp13.200,00
		6200	4 Pcs	Rp2.200,00	Rp8.800,00
		6208	1 Pcs	Rp90.000,00	Rp90.000,00
		6302	9 Pcs	Rp32.500,00	Rp292.500,00
5	Bearing Cover	UCF 205	4 Pcs	Rp30.000,00	Rp120.000,00
6	Blade Base	5mm Steel	245819,89	mm	Rp0,74
7	Bracket	10mm Steel	12004,362	mm	Rp2,40
8	Bridge x3	5mm Steel	40501,135	mm	Rp0,74
9	Chain with Sprocket		1 Pcs	Rp900.000,00	Rp900.000,00
10	Drive Wheel		1 Pcs	Rp300.000,00	Rp300.000,00
11	Electric Motor	Y132S-4 brushless ac 3 phase motor	1 Pcs	Rp3.000.000,00	Rp3.000.000,00
12	Emergency Button		1 Pcs	Rp60.000,00	Rp60.000,00
13	H Beam	200 UC 46	5 m	Rp3.214.776,02	Rp16.073.880,10
14	Legs	50x50x5 1000mm	4000 mm	Rp159,00	Rp636.000,00
		50x50x5 800mm	3200 mm	Rp159,00	Rp508.800,00
		50x50x5 600mm	2400 mm	Rp159,00	Rp381.600,00
15	Loader	5mm Steel	834569,287	mm	Rp0,74
	Machine Cover				
16	Frame	Hollow Beam 10x30	15637 mm	Rp35,00	Rp547.295,00
		Hollow Beam 10x50	40000 mm	Rp18,33	Rp733.200,00
		Hollow Beam 20x50	10000 mm	Rp20,00	Rp200.000,00
	Machine Cover				
17	Sleeve	3mm Stainless Steel	5243985,47	mm	Rp2,50
	Moving Cover				
18	Frame	Hollow Beam 10x20	2716 mm	Rp20,00	Rp54.320,00
		Hollow Beam 10x30	284 mm	Rp35,00	Rp9.940,00
	Moving Cover				
19	Sleeve	3mm Stainless Steel	376520,008	mm	Rp2,50
20	Shaft		1 Pcs	Rp300.000,00	Rp300.000,00
21	Shaft Holder	UCP 204	1 Pcs	Rp32.000,00	Rp32.000,00
22	Short Shaft		1 Pcs	Rp300.000,00	Rp300.000,00
23	Small Drive Wheel		1 Pcs	Rp300.000,00	Rp300.000,00
24	Splitter Blade	5mm Steel	36060,116	mm	Rp0,74
		10mm Steel	16185,362	mm	Rp2,40
25	Sprocket		2 Pcs	Rp50.000,00	Rp100.000,00
26	Pillow Block "T207"	UCT 207	2 Pcs	Rp90.500,00	Rp181.000,00
27	Acrylic Window	3mm Acrylic	18068,21	mm	Rp0,24
28	Belt		1 Pcs	Rp300.000,00	Rp300.000,00
TOTAL COST					Rp42.175.466,34

The price estimation of this bamboo splitter machine is around Rp42.175.466,34 excluding the assembly, manufacturing, and development cost. The price can be lowered depending on where to buy the raw materials.

CHAPTER 5

DISCUSSION

5.1 Attribute Analysis of Bamboo Splitter Machine Development

Based on the results of data collection using the questionnaire method conducted on 20 respondents who work in the bamboo industry, it was found that consumer desires for bamboo splitting machine products are as follows: Process time, Safety, Durability, Precision, Easy to use, Customization, Affordability, and Portability.

The consumer's desire for the process time attribute indicates that the consumer wants a machine that can process bamboo in a short time. To interpret the consumer's desire that the bamboo splitting machine can process bamboo in a short time, that is by using a mechanism that is often used in bamboo splitting machines on the market, namely by using a push mechanism. The pushed mechanism in the developed machine is improved a bit in the parts that connect the pusher with the chain that drives the machine. It is to improve the lifetime of the pusher and reduce the damage to the pusher.

Next is the desire of consumers for safety attributes which indicates that consumers want safety features for operators when operating this bamboo splitting machine. To interpret the safety attributes of this bamboo splitting machine according to the wishes of consumers is to add a machine cover made of metal that can protect the operator, there is also a moving cover with the same function as the cover, except that the moving cover can be opened and closed to make it easier to access parts in this machine. There is also an emergency stop button to stop machine operation instantly if a problem occurs which could endanger the operator or endanger people around the machine.

Next is the consumer's desire for the durability attribute indicating that consumers want a machine that is durable and long-lasting. To interpret the durability attribute of this bamboo splitting machine is to use a layer of anti-rust paint on all the frame components, and some of the main components. Using a layer of anti-rust paint on this machine is expected to extend the life of the machine. In addition to the use of anti-rust paint, several parts of the machine have also made design changes to increase the durability aspect, such as the bamboo pusher, the position of the "T207" part has also been changed by 180 degrees to change the force received which was previously a pulling force to a pushing force.

Next is the consumer's desire for the precision attribute indicating that the consumer wants a precision machine for splitting bamboo. To meet consumer needs for precision attributes, namely by adding a part of the Bamboo guide which has been positioned in such a way as to be parallel to the blade of the splitter. The splitting knife is also added with a "V" shaped iron so that the bamboo stays in a balanced position when in contact with the blade.

The next consumer desire is for the easy-to-use attribute indicating that consumers want a machine that can be easily operated and can also be easily replaced with spare parts. To meet consumer needs for easy-to-use attributes, namely by using a simple mechanism by directly connecting the machine with an electric drive motor, only by turning on the electric drive motor the machine can be operated. In addition, this machine also uses spare parts that are widely sold in the market, so that if there are parts that need to be replaced, consumers can easily buy these parts and replace the damaged parts without contacting the machine maker.

The next consumer desire is for the customization attribute which shows that the consumer wants a bamboo splitter that is easy to customize. To meet consumer needs for customization attributes, the blades on the bamboo splitting machine can be replaced easily, also many parts of the machine are connected using bolts, so consumers can customize this bamboo splitter easily.

The next consumer desire attribute is the affordability attribute which indicates that consumers want this bamboo splitting machine to be affordable and cheap. Therefore, several parts for this machine already exist and are widely sold in the market. Therefore, there are no additional costs for research and development, as well as the high costs for fabricating special parts which are also complicated. Using a simple mechanism that is the push mechanism has reduced the cost of this machine itself.

Furthermore, the consumer's desire for the portability attribute indicates that the consumer wants a bamboo-splitting machine that can be moved easily. Based on the results of the product questionnaire in the first stage, the portability attribute has a very small weight compared to the other attribute weights, namely only with an IR value of 1.9. Then the results of data processing on the house of quality matrix obtained a row weight value of 3.3, which is considered as the smallest row weight value compared to other attributes. Also based on the results of benchmarking with competing products, it is known that only one competing product has portability attributes, namely the bamboo splitter machine (Sutanto et.al., 2019), apart from

that all bamboo splitting machines do not have portability attributes. Therefore, the design of this bamboo splitting machine also does not use portability attributes.

5.2 Quality Function Deployment (QFD)

5.2.1 House of Quality (HOQ)

1. Importance Rating

Determining of design parameter of the bamboo splitting machine in this research is conducted using Quality Function Deployment (QFD). The first step in the QFD method is to do a survey using a questionnaire to find out what is needed and customer requirements to develop this bamboo splitting machine. The output of this survey will be the customer needs which will be translated into a design attribute for the bamboo splitting machine. The next step is to determine the importance rating of each attribute. The attribute that has been calculated for the importance rating is Process Time attribute with IR value of 4.8, Safety with IR value of 4.7, Durability with IR value of 4.7, Precision with IR value of 4.8, Easy to use with IR value of 4.6, Customization with IR value 4.5, Affordability with IR value 4.6, and Portability with IR value 1.9.

2. Technical Requirements

After the importance rating is acquired, the next step is to translate the customer needs into technical requirements to know the technical criteria which will use to develop the bamboo splitting machine. Customer requirements of “Process Time” are translated into “Machine Rpm”, “Machine Powe Output”. Next is customer requirements of “Safety” are translated into “Machine Cover” and “Emergency Button”. customer requirements of “Durability” is translated into "Durable Material". customer factor “Easy to Use” translates to “Machine Size”, and “Use Pushing Mechanism”. Next customer requirements “Precision” is translated into “Use Pushing Mechanism”, and “Add Guiding Rail”. Customer needs of “Customization” translate to “Interchangeable Blade”. Customer factor of “Affordability” translates to “Use Pushing Mechanism”. And last customer requirement of “Portability” translates to "Easy to Move”.

3. Relationship Between Customer Requirement and Technical Requirement

After the customer requirements are translated into technical requirements, the next step is to determine the relationship between customer requirements and technical requirements. The relationship value can be determined using relationship level which is a weak relationship (1

point), medium relationship (3 points), and strong relationship (9 points). Customer requirement of Process time has a strong relationship with “power source”, and “implemented technology”, a medium relationship with “customizable factor”. Customer requirement for Safety has a strong relationship with “strong material”, and “safety factor”, a medium relationship with “implemented technology”. Customer requirement of Durability has a strong relationship with “strong material”, and “implemented technology”, and a weak relationship with “customizable factor”. The next customer need is Precision, Precision has strong relationship with “implemented technology”, and a medium relationship with “customizable factor”. For Easy to use, it has a strong relationship with “ergonomic”, and “implemented technology”, a medium relationship with “portability factor”, and a weak relationship with “customizable factor”. The next customer needs is Customization, Customization has strong relationship with “customizable factor”, and medium relationship with “implemented technology”. Customer requirement of Affordability has a strong relationship with “strong material”, “size”, “power source”, and “implemented technology”, and a medium relationship with “safety factor”, and “portability factor”. And the last customer requirement is Portability, Portability has a strong relationship with “size”, and “portability factor”, and a weak relationship with “strong material”, and “ergonomic”.

4. Determine Target Value

After translating the customer needs into technical requirements and determine their relationship. Then we can determine the target value for each technical requirement. Technical requirements of “Machine Rpm” has a target which is to use a moderate Rpm machine. Requirements of “Machine Power Output” has the target of using a machine with moderate power output. Next is the requirement of “Machine Cover” which has a target to add a cover for safety which translates to the machine with a metal cover span over 5 meters. The requirements of “Emergency Button” has a target to add an emergency button for safety measures. Technical requirements "Durable Material" has a target to use high carbon steel as the material for the machine. Technical requirements of “Machine Size” have a target to have a sufficiently high, so the machine will fit with local Indonesian measurements. The next requirement is “Use Pushing Mechanism” have a target to use a pushed mechanism as the mechanism of the machine. The requirement of ”Add Guiding Rail” have a target to add a guide rail for the bamboo, so the operation will be easier for the operator. The next technical requirement is “Interchangeable Blade” which has a target to have the blade interchangeable

for easy operation. The last requirement is “Easy to Move” has a target to add a wheel for higher portability.

5. Customer Competitive Evaluation

The next step is to calculate the customer competitive evaluation of each customer's needs of our proposed bamboo splitting machine, the first attribute is process time, the customer competitive evaluation score is 4 which is the same as the machine that is commonly available in the market, the company can increase this attribute but not much. Next is safety which the customer's competitive evaluation score is 5 which already surpassed the other competitor machine, company would not improve this attribute because it already surpassed other machines in the market. The next attribute is durability which the customer's competitive evaluation score is 4, The company will not improve it since it already surpassed the machines from competitors with the score of 3. The next attribute is Precision which the customer's competitive evaluation score is 3, in this attribute company can increase these attributes because the score is still the same as the other machine from the competitor. Easy to use is the next attribute, the customer competitive evaluation score for this attribute is 4, which is the same as the machine in the market, then company can increase these attributes. The next attribute is Customization, the customer competitive evaluation score for this attribute is 4, which already surpassed the score of the competitors, so the company is unnecessary to do any improvements. The next attribute is Affordability, the customer competitive evaluation score for Affordability is 3, which is below the score of the competitors, therefore the company should do improvement on this attribute. And for the last attribute is Portability, the score of customer competitive evaluation for Portability is 1 which is the same as the majority of the competitor, so the company is unnecessary to do any improvement on this attribute.

6. Determine the Sales Point

Sales point is an attribute that defines the product have a high sale point, especially for selling the product. Following are the attributes that seen can become the sales point of this product which are Process time, Safety, Durability, and Customization.

7. Improvement Ratio

The improvement Ratio is used to show how drastically the changes or the improvement that needs to do. As we can see in Table 4.24, it shows the improvement ratio of each attribute of our bamboo splitter machine. Many of those scores are below 1 which does not need any

change or improvement such as “process time”, “safety”, “durability”, “precision”, “easy to use”, and “customization”. The attribute that needs a moderate change is “affordability”, and attribute that needs a high change is “portability”.

8. Row Weight

Next is the row weight for each design attribute. Row weight is used to show the improvement of customer needs attribute. The highest row weight value is 6.1 which is from the attribute of affordability, which means bamboo splitting machine that affordable is very needed. Then the lowest row weight value is from the portability attribute with a value is 3.3, which shows us that the consumer does not need a portable and easy-to-move bamboo splitting machine.

9. Action

This is the last step in the House of Quality matrix which is to determine the action needed for each attribute. A category means the attribute will become the priority to improve the quality of the product, an attribute that categorizes as A is “affordability” which means the affordability needs to be improved. B category means the quality of the current product will be maintained and will continuously be innovated, attributes that categorize as B is “process time”, “safety”, “durability”, and “precision”. It means those attribute quality will be maintained and will be continuously improved. The last category is C means the quality is needed to be maintained without any further improvement, attributes that categorize as the C category are “easy to use”, “customization”, and “portability”, which means those attributes' quality will be maintained.

10. Part Deployment Matrix

Part deployment matrix is a tool used in Quality Function Deployment (QFD). This step helps the researcher to identify which parts of the product are most critical to customer satisfaction and which requirements are most important for each part. This part is also a continuation of the house of quality matrix before. To determine the critical part requirement a method called fault tree analysis is used. The critical technical factor is “Rpm 750-300”, “3Kw-5.5Kw power output”, “Hollow Beam”, “Aluminium Sleeve”, “Emergency Button”, “High Carbon Steel”, “Use Local Average Height”, “Improved Pusher Design”, “Add a Wheel”, and “Electric Generator”.

After determining the critical part, then we determine the relationship between the technical requirement and the critical part requirement which is shown in Figure 4.8. Based on that figure the tree attributes that have the highest relative weight is “Interchangeable Blade”, “Using

Pushed Mechanism”, and “Add Guide Rail” which means those attributes need to be planned much better than other attributes.

For the relationship itself, the rating system is the same as for the house of quality, which a weak relationship (1 point), medium relationship (3 points), and strong relationship (9 points). For technical requirements of the Machine Rpm has strong relationships with “Rpm 750-3000”, and “Electric Generator”, and medium relationships with “3Kw-5.5Kw power output”. Technical requirements of machine power output have strong relationships with “3Kw-5.5Kw power output”, and “Electric Generator”, a medium relationship with “Rpm 750-3000”. Machine cover requirements have strong relationships with “Hollow Beam”, and “Aluminium Sleeve”. Emergency buttons have strong relationships with “Emergency Button”. Technical requirements of durable material have a strong relationship with “High Carbon Steel”. Machine size requirements have a strong relationship with “Use Local Average Height”. The utilization of pushing mechanism requirements have a strong relationship with “Improved Pusher Design”, a medium relationship with “High Carbon Steel”. Add guide rail requirements have a strong relationship with “High Carbon Steel”, a medium relationship with “Improved Pusher Design”. Technical requirements of interchangeable blades have a strong relationship with “Improved Pusher Design”, a medium relationship with “High Carbon Steel”. Lastly easy-to-move requirements have strong relationships with “Add a Wheel”.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, the following are the result of this research consisting of analysis and discussion. Below are the conclusions that are obtained.

1. The customer preference for this bamboo splitter machine is Process time, Safety, Durability, Precision, Easy to use, Customization, Affordability, Portability.
2. The specification and design of a new machine to process bamboo fencing is an improved version of the bamboo splitting machine which already on the market, the changes include:
 - a. Adding of metal cover for safety which spans over 5000 mm, 345.997 mm width, 503 mm high, and 10 mm thick with a 3 mm sleeve to cover the machine. There is also a moving cover to easily access the inner part of the machine, with a length of 328 mm, 393.828 mm in height, and 375.997 mm in width. Include a handle to move the cover easily.
 - b. The pusher part is there with some improvement in shape, dimension, and features to eliminate the current problem which the pusher is easily damaged in the area that connected the pusher with the chain.
 - c. The improved mechanism that connects the pusher with the chain.
 - d. The base for the blade is adapted to the design which needed the blade to be interchangeable easily.
 - e. A bamboo guide is added to make the operation easier, it is there so the operator does not require to hold the bamboo until the pusher pushes it thru the blade. The guide is having a stand to be positioned parallel to the blade.
 - f. The loader and bridge are also there to make the machine semi-automatic, so the operator just needs to put the bamboo into the loader and leave it there.
 - g. The position of “T207” is changed to change the force that previously is pull force to become push force.
 - h. The electric motor is also used to power this machine, which can generate speeds up to 3000 RPM.
 - i. The emergency stop is added to stop the machine instantly if there is any mishap.

6.2 Recommendation

Based on this research, a recommendation for further research is to add a device to control the speed of the machine or a speed profile based on the type and the thickness of the bamboo that will be processed. The other is to add an easy-to-maintain aspect of the machine to know if the machine is easy enough to maintain than the other machine. Next is to conduct a more detailed deep analysis of this machine's design to identify how the real performance of this machine, whether the performance or the durability is improving. Moreover, further research is to continue the Quality Function Deployment to the third house which is an operating matrix, and the fourth house which is a control matrix.

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