THE DEVELOPMENT OF A FISHPOLE BAMBOO PERFORATION MACHINE USING QUALITY FUNCTION DEPLOYMENT

UNDERGRADUATE THESIS

Submitted as One of The Requirements to Obtain a Bachelor's Degree in The Industrial Engineering Study Program, Faculty Of Industrial Technology

Name : **Sabila Rizki Alifian**

Student Number : **18522322**

INTERNATIONAL UNDERGRADUATE

PROGRAM IN INDUSTRIAL ENGINEERING

DEPARTMENT OF INDUSTRIAL ENGINEERING

UNIVERSITAS ISLAM INDONESIA

YOGYAKARTA

2023

STATEMENT OF AUTHENTICITY

In the name of Allah SWT, I acknowledge that this work is my own except for the parts where I have clearly stated the source. If it is discovered in the future that my statement is false and goes against the legal regulations regarding intellectual property rights, then I am willing to have my diploma from the Islamic University of Indonesia revoked.

Yogyakarta, March 15th 2023

Sabila Rizki Alifian

RESEARCH COMPLETION LETTER

SURAT KETERANGAN PENELITIAN

Yang bertanda tangan dibawah ini, pemilik dari PT. Dekorasia Jayakarya Indonesia menerangkan bahwa:

Nama	:	Sabila Rizki Alifian
NIM	:	18522322
Program Studi	:	Teknik Industri IP
Perguruan Tinggi	:	Universitas Islam Indoensia

Adalah benar nama tersebut diatas telah melaksanakan penelitian di PT. Dekorasia Jayakarya Indonesia terhitung mulai tanggal 1 Februari 2022 s/d 29 Februari 2023 dalam rangka penyusunan skripsi dengan judul:

"The Development of Fishpole Bamboo Perforation Machine using Quality Function Deployment Method."

Demikianlah Surat Keterangan ini dibuat dengan sebenarnya untuk dipergunakan sebagaimana mestinya.

Yogyakarta, 29 Maret 2023
Owner PT Dekorasia Jayakarya Indonesia

Bambang Wijaya

THESIS APPROVAL OF SUPERVISOR

THE DEVELOPMENT OF A FISHPOLE BAMBOO PERFORATION MACHINE USING A QUALITY FUNCTION DEPLOYMENT METHOD

UNDERGRADUATE THESIS

By

Name : Sabila Rizki Alifian

Student Number : 18522322

Yogyakarta, March 2022

Supervisor

Ir. Muhammad Ridwan Andi Purnomo, S.T., M.Sc., Ph.D.

EXAMINERS' APPROVAL PAGE

THE DEVELOPMENT OF FISHPOLE BAMBOO PERFORATION MACHINE USING QUALITY FUNCTION DEPLOYMENT METHOD

UNDERGRADUATE THESIS

Written by:

Name : Sabila Rizki Alifian

Student Number : 18522322

Has been defended before the board of examiners in partial fulfillment of the requirement for Bachelor Degree in Teknik Industri at the Faculty of Industrial Technology Universitas Islam Indonesia

Yogyakarta, April 2023

Board of Examiners:

Ir. Muhammad Ridwan Andi Purnomo, S.T., M.Sc., Ph.D., IPM.	
Chairman	
Winda Nur Cahyo, S.T., M.T., Ph.D.	
Member I	
Dr. Agus Mansur, S.T., M.Eng.Sc.	
Member II	

Acknowledged by,

Head of Undergraduate Program in Industrial Engineering Faculty of Industrial Technology Universitas Islam Indonesia

Ir. Muhammad Ridwan Andi Purnomo, S.T., M.Sc., Ph.D., IPM

DEDICATION PAGE

Bismillahirahmanirrahim

Gratitude and all the author's energy say for this thesis.

I dedicate it to my parents,

Mr Muhammad Wahid

Mrs Barokah

To my beloved brother,

Ihwan Fajar Maulana.

For friends

as well as those who help either directly or indirectly.

And I dedicate it to myself who is still surviving and fighting to this day.

MOTTO

“Everything that I know, is I know nothing.”

- Sabila Rizki

“One who treads a path in search in knowledge has his path to paradise made easy by God”

- Riyadh -us- Saleheen, 245

"Happiness is not something ready-made. It comes from your own actions."

- Dalai Lama

PREFACE

Assalamualaikum Wr.Wb.

Alhamdulillah, all praised Allah who granted His blessing, grace, and strength so the author could complete the undergraduate thesis.

This thesis is dedicated to all students, especially in the Industrial Engineering department which focused on product and machine design. Also, this thesis has become one of the requirements to finish the study in the International Program of Industrial Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia. All support and consultation come in the form of moral and material support, either directly or indirectly given as long this thesis is developed. Thus, the author would give a bunch of thanks to:

1. My beloved family, my father (Muhammad Wahid), mother (Barokah), brother (Ihwan Fajar Maulana), and other families give invaluable supportive spirit.
2. Mr. Prof. Dr. Ir. Hari Purnomo, M.T. is a Dean of the Faculty of Industrial Technology, Universitas Islam Indonesia.
3. Mr. Muhammad Ridwan Andi Purnomo, S.T., M.Sc., Ph.D. as the thesis supervisor as well as the Head of the Industrial Engineering Department, Universitas Islam Indonesia with the best support, guidance, and inspiration.
4. Mr. Bambang Wijaya, as the owner of PT. Dekorasia Jayakarya for the kindship of the opportunity given to conduct the research in PT. Dekorasia Jayakarya.
5. Anes, and the high school besties members of the “Opo Iki” group (Pandum, Bayu, Luqman, Astrid, Dea, Dyah, Avien, Sofi, Zulfa) for their help, motivation, and kindful support for this research in all situations.
6. The colleagues, best friends of “Prague/Corsair” (Aan, Faiq, Naufal) for the best support, togetherness, and kindest spirit.
7. The friends from the Industrial Engineering International Program especially class batch 2018, for the togetherness and support that cannot be mentioned one by one.

8. The friends from the Integrated Manufacturing System (SIMAN) Laboratory especially fellows of batch 2018 or members of the “Anjay Bubar” group (Alya, Indika, Fahrul, Lukman, Shandy, Ari) for their spirit, kinship, and motivations.
9. The friend of “Pencari Café Hidden Gem” (Verrel and Nabila) for their kindful spirit and motivation.

The Authors additionally express their gratitude to all concerned parties who have assisted in finishing this thesis but who cannot be named one by one. Hopefully, Allah's goodness will provide the things. Finally, acknowledges that there are still flaws and limitations in the Author's research, thus constructive criticism and recommendations are eagerly anticipated. The author hopes that everyone who reads this will benefit from it.

Wassalamualaikum Wr.Wb

Yogyakarta, March 15th 2023

Sabila Rizki Alifian

ABSTRACT

Bamboo is a widely used material in many industries due to its versatility, strength, and sustainability. Fishpole bamboo, in particular, is a popular choice for various applications, including furniture, handicrafts, and construction. PT Dekorasia is the decoration manufacturing company that makes the product using fishpole bamboo as well. However, the process of perforating bamboo poles for these applications is time-consuming and labor-intensive, leading to high production costs and low productivity. In this study, a fishpole bamboo perforation machine was developed using the quality function deployment (QFD) methodology. The machine's requirements are defined by considering various parameters, such as progressive, durable, safe, ease of use, compact, and low cost. The results showed that the product is developed with characteristic specifications and parts based on the customer's requirements. In conclusion, the machine's design ensures that customer needs are met while optimizing performance.

Keywords: Perforation Machine, QFD, Participatory Design, Laser

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

1.1 Background

Bamboo plays a major role in worldwide livelihood. Bamboo is a multifunctional plant that can easily be utilized in several kinds of products around the world. Carbon brisket, building material, processed food, household utensils, and decoration is examples of how various bamboo utilization is. Bamboo belongs to the Gramineae (grass) family, also called Giant Grass, in groups and is composed of a series of stems that grow gradually, from shoots to young stems, and mature at the age of 4-5 years. Bamboo roots consist of rhizomes with nodes and segments, segments will be covered with fibers and shoots that can become stems (Widnyana, 2017). Of about 1,000 bamboo species in 80 genera, about 200 species of 20 genera are found in Southeast Asia, while about 60 species are found in Indonesia. Indonesian bamboo plants are found in the lowlands up to the mountains with an altitude of about 300m above sea level. (Arhamsyah, 2016). That is why bamboo is suited to easily grow in Indonesia and has already been utilized by a wide society.

Bamboo grows by spreading its root in the form of a rhizome underground that will be grown up (Arsad, 2016). The growth of bamboo is so easy to spread and grow makes it might be invasive if there is no further action from society. The common society is already taking advantage of the typical growth of bamboo itself which can be utilized in several beneficial and value-added products. The young bamboo shoot is known to be a recipe for a famous Indonesian cuisine named Lumpia. Moreover, Widnyana (2017) stated that bamboo material is known to have that suits to be utilized such as having a strong stem, ductile, straight, flat, hard, easy to split, easy to shape and easy to work with, and light. In the daily

life of Indonesian society, bamboo has been utilized in various kinds of utilization from the use of small scale to the industrial scale. Common bamboo utilization found in Indonesian society is usually using a simple technology to process bamboo into a finished product. A full round bamboo is usually used for some construction matters such as a house, a shed, plumbing, a water container, and household utensils. On the other hand, split shape bamboo is utilized in the shape of cubicles, walls, floors, batten, and fences (Ministry of Forestry , 2014). The bamboo decoration is one of the popular utilization of bamboo. As a household product, bamboo can be processed into several matters that bring additional value. Bamboo panels, bamboo root decoration, bamboo fences, and a bamboo gazebo are examples of how many products can be made from bamboo utilization (Bambang, 2022). However, on an industrial scale, bamboo is often processed to become an export product that must be fulfilled a certain number of customer demands.

After China and India, Indonesia is the third country in Asia with a large supply of bamboo resources with a record export value reaching Rp. 6 trillion (Rosadi, 2015). Bamboo may be used as a substitute for wood in the construction of buildings, furniture, flooring, and a variety of other bamboo items. It can also be utilized as a biomass energy source and as a raw material for pulp and paper. Bamboo goods from Indonesia have been exported in a variety of forms, including bamboo sticks (used largely for plaiting), bamboo charcoal, bamboo flooring, bamboo plywood, bamboo mats and screens, bamboo plaits and plaiting items, bamboo pulp, and bamboo paper products. In accordance, according to the statistics, bamboo flooring, bamboo plywood, bamboo mats, and screens, as well as wicker and bamboo woven products, are in a growth stage of competitiveness. Bamboo sticks and bamboo charcoal, on the other hand, have significant competition and are in the maturity stage (Simbolon, 2019).

PT Dekor Asia Jayakarya is one of the industrial-scale bamboo utilizer that run for utilizing forestry resources in several products that are sold in local communities and abroad. Despite all of those advantages of bamboo, the physical and mechanical qualities, the non-uniformity of the length of the segments, and the incapacity to survive against destructive creatures are the most significant aspects of the community's usage of bamboo. Furthermore, it must be noticed that in order to fulfill the worldwide demand, a high-level production must be run beside the bamboo material deficiency. However, how to manage that bamboo

production to be met customer demand is challenging. From the current observation, it is known that PT. Dekor Asia Jayakarya still uses manpower and traditional technology for its business process. Moreover, according to the interview with the company owner, the company needs to increase manufacturing productivity as a way to compete with the international market. In 2021, PT. Dekor Asia Jayakarya receives 20 containers per month but is only able to fulfill 15 per month or there is a 5-container gap between production capacity and. On the other hand, the company has the value of community empowerment so they continue to strive to employ the community. The common problem-solving might suggest increasing the number of manpower in the production line. But it just increases the cost and yet doesn't increase company productivity. It requires a tool that can easily be used by the employee that is able to improve the production performance of the cendani bamboo-making process, so the production might increase but the cost still can be suppressed.

Machine design is an important activity in order to reach production ideality. According to Sabhadiya (2021), machine design is needed to design the machine that will be used for productivity improvement. The product design step will be determining the success or failure of a company. However, the designer must be seeking the machine's stakeholders' needs with respect to the environment's adaptability.

There are several methods of product designing that can be used for product development research such as Quality Function Deployment (QFD), Kano, Kansei Engineering, and TRIZ. Accordingly, there is a need to find good physical and technical specification requirements based on the stakeholder's needs. Thus, being able to transform the needs into several product parameters requires the QFD method to support the product development process. So the process of designing the ideas to solve the bamboo cendani holing process can consider its function and considering the technical requirement.

In supporting the development process to be more specific and closer to the company, the participatory design is adopted. Brandt & Messeter (2018) stated that participatory design is a research approach that involves actively involving users or stakeholders in the design process to ensure that the resulting product meets their needs and expectations. Participatory design is aligned to the Quality Function Deployment (QFD) in order to obtain the specific design characteristic based on the direct involvement of stakeholders in the development research.

Based on the explanation beforehand, the research is aimed to develop a bamboo perforation machine with the QFD method in PT. Dekorasia Jayakarya. This research is hopefully able to initiate the increase of production capacity in the company in order to compete with the foreign markets.

1.2 Problem Formulation

According to the problem description in the background, the problem formulation for this research is how the design prototype of the bamboo cendani perforation machine using the QFD method.

1.3 Research Purposes

The purpose willing to be achieved in this research is to find the shape of the designed prototype of the bamboo cendani perforation machine using the QFD method which is able to improve production capacity in PT. Dekorasia Jayakarya.

1.4 Scope of Problem

The scope of the problem in this research works as a limitation to what will be researched and discussed in this study, so it might not cause any problems or questions outside of this research. However, the scope of the problem in this research such as:

1. The object of this research is to focus on the production process of bamboo cendani, especially on the perforation process of bamboo cendani making in PT. Dekorasia Jayakarya.
2. The research limitation is to design a proposed prototype for functional design for a bamboo cendani perforation machine in the shape of a visual design that is processed using Solidworks 2022 software.
3. This research is using QFD method in order to perform with research objectives.

1.5 Assumption

The assumption that imported in this research is the performance result that is obtained from the testing and research on Manufacturing System Laboratory can be assumed as a similar performance result for a similar machine specification.

1.6 Research Benefit

The following are benefits gained from this research is such as:

1. Education

   For the education field, this research is beneficial as a way to test and implement the theory that has been conducted before. However, for the student, it is beneficial to implement the knowledge that has been studied in college.

2. Company

   This research is hoped might arise benefits to the company in the form of a way to improve the business process, especially the production process in the bamboo cendani process making. This can be an improvement for the company in order to compete with the international market by improving the company's productivity.

1.7 Systematic Writing

To maintain this research to be structured, then the research must have systematic writing to provide clarity regarding the composition of the research. The systematic writing on this research is as follows:

CHAPTER 1 INTRODUCTION

This chapter will be discussing the problem's background, the problem formulation that will be discussed, the research objectives, the scope of the research, the benefits get from the research, also the research systematic writing.

CHAPTER 2 LITERATURE REVIEW

The literature review consists of deductive study and inductive studies. The deductive study work as a research reference which is a theoretical review that is related to this research. However, the inductive study is a review of the previous research that correlates with the research that is conducted.

CHAPTER 3 RESEARCH METHOD

In this chapter, the framework and research flow of this research will be explained, including the method steps that will be used. So that the research carried out has a clear flow.

CHAPTER 4 DATA COLLECTION

The 4th chapter will contain the data required that will be collected, also data processing after the data has already been collected.

CHAPTER 5 DISCUSSION

This chapter will be discussing the result of the data that has been processed and discussing its correlation with the research objectives.

CHAPTER 6 CLOSURE

This chapter consists of the research conclusion and research suggestions from this research.

CHAPTER II

LITERATURE REVIEW

2.1 Inductive Study

The inductive study consists of previous research that has similarities with corresponding research according to its methodology or even its object that is willing to be compared. The affirmation of a statement of art is needed to prove that the research conducted is new or it is the most up-to-date research.

Siswadi (2021) researched the development of an ergonomic machine for the "Opak Jepit" product using Quality Function Deployment (QFD) method. The process of the research is starting with direct observation to observe the field condition of the small-medium enterprise "Opak Jepit" producer in Wonoayu, Sidoarjo. The second step is by doing a direct interview with the enterprise's stakeholders such as the employee and the owner to find the technical attribute and machine specifications. The third step is by doing an interview with the machine developer to find the technical attribute response. The technical attribute response is the machinery technical attribute that is customized according to machine specifications. The fifth step is to score the important rating of the attributes that have already been collected in the form of a questionnaire. The result shows that took into account consumer desires in order of greatest priority, starting with the durable engine design attribute with a weight of 0.199 and ending with the easy-to-clean attribute with a weight of 0.048. The technical response priority order by the priority in order is the ergonomic size and size attribute with a correlation degree score of 39. However, the last priority attribute of technical response is spring opening and electric heating with a linkage score of 1.

Albertus (2020) conducted research on the phone charger product development analysis using the QFD method. This research uses Quality Function Deployment 4 phase

(QFD 4) method. The first phase is the development of the House of Quality (HOQ) based on customer attributes. The second phase is product designing which converts the technical response from the previous phase into a part characteristic. The third phase is process planning displayed by a flowchart and then continued into process parameters. The last phase is production planning supervised through indicator performance and production schedule. As a result, it obtained 6 attributes and 6 technical characteristics. The product's characteristic material remains pricy considering the price and tricky in considering the difficulties. However, the other characteristic is considered as cheap in price and easy in its difficulties.

Li, Guo, & Cao (2018) conducted research on the optimization of laser cutting parameters for recombinant bamboo based on response surface methodology. The methodology used for this research is response surface methodology. The recombinant bamboo with 3 different thicknesses was cut by a laser cutting machine and there are 3 parameters compared which are the cutting efficiency, including upper and lower kerf, and the ratio of upper to lower kerf. The mathematical model is developed to measure the relationship of the response parameter based on the process parameter. As a result, the optimization is performed to find the optimized process set up to achieve a minimum upper-lower kerf ratio.

Suartika, Alit, & Aprentari (2018) doing research regarding the development of a corner seat in bamboo utilizer small-medium enterprise using quality function deployment. The QFD method is used to identify a customer's wants. The customer wants is gain from the voice of customers found by a questionnaire data collection. The questionnaire is shared with 90 respondents from 3 small-medium enterprises customers. The voice of the customer is shared with the aim to get an insight into the product that the market needs. So, small-medium enterprises can develop a product based on the needs of the market. According to the research result, from 1 old design and 2 types of new designs, the design that has more interest from the customer is the new design.

Erlangga (2018) conducted research on the development of an oil-draining machine using TRIZ. The step that is conducted by this method is first, selecting the technical problem of the current condition. The second step is to formulate a physical contradiction and the third

step is to formulate the ideal solution. The fourth step is to find a resource for a solution and use it for the capability of TRIZ. The next step is determining the strength of the solution and predicting the development of the system. The last step is to analyze the solution process to prevent a similar problem from re-occurred The result from the questionnaire that was processed using the TRIZ method obtained five design attributes wanted by customers, which are the simple but attractive design with a simple spinner component, practice for its usage, silent machine, a speed setting feature, and save using.

Research by Chrisdio & Benedikta (2020) tried to design a smart class model for a table set. The type of development efforts is being done in this situation since the design of computer desks and chairs was created utilizing the Quality Function Deployment (QFD) approach, which is utilized to construct the home of quality. A sample of 112 respondents was used for data collecting in order to develop the house of quality. Based on the QFD method's application from the anthropometric approach and the 8 dimensions of quality, potential users give priority to the reliability dimension, which calls for a safe table, the durability dimension, which calls for high-quality table materials, and the feature dimensions, which call for additional features on a computer desk that is made. In order to achieve this, priority development must be made, starting with the selection of a table size that is appropriate and ending with the sort of material that best satisfies customers' top priorities, namely high-quality table materials.

Nurmianto, Wessiani, & Megawati (2018) conducted research for the development of fish smoking tools. This research was conducted using two different processing data. The first data in the form of Voice of Customer data will be processed using the QFD method. Subsequent data from the results of organoleptic testing were processed using Microsoft Excell software. The result obtained is to prevent the fish from sticking when being turned or taken out of the fish smoking container once it has cooked, a tray is placed in the fish smoking container. The smoke source's distance must be adjusted because if it is too close to the smoking container, the fish will cook quickly and the maturity's effects won't be uniformly spread throughout the smoked fish.

Research by Paulina & Ketut Purnawati (2018) explaining the design of service products using QFD. The tool used in service design is Quality Function Deployment with the House of Quality, which, in addition to knowing the company's position in the market, connects customer desires and the company's capacity to respond to them. 115 people were selected through purposeful sampling from the study population, which consists of all customers of PT. X and its rivals. As seen by the gap between client interest and company performance, findings indicate that PT. X has not been able to satisfactorily satisfy customer demands or requirements. The position of PT. X is still behind its rivals and requires development in order to raise customer satisfaction. There are 7 service indicators that translate into customer requirements and 7 technical requirements.

The research conducted by Maimunah, Lisha, & Atsari (2019) discusses the redesign process of brownies packaging using the Quality Function Deployment (QFD) method. The research is aimed to expand market segmentation and fulfilling market demand. The results showed the attributes that customers wanted product capacity, graphic design, dimensions, shape, strength, and durability of the packaging. The technical responses are modern visual design, attractive colors, clear information, dimensions according to capacity, more product contents, ergonomic packaging forms, and thicker and stack-resistant packaging materials that are not easily damaged.

Sanny & Prima (2018) researched the development of a shredder machine for goat dung using the QFD method. The goal of the study is to create a goat dung crusher that will maximize the decomposition of goat manure. Goat dung crushing device was created using the Quality Function Deployment approach (QFD). The standard time for the new goat dung crusher, which has dimensions of 71 cm in length, 45 cm in breadth, and 98 cm in height, is 3.05 minutes per kilogram in order to generate an output standard of 20 kg per hour. By examining the data, it was possible to calculate a 900% rise in percentage.

Ginting, Batubara, & Widodo (2017) had research regarding the development of redesigning multifunctional tissue cases by implementing the QFD method. In this study, QFD was utilized as a quality control measure for a product based on customer requirements and wants. A multifunctional tissue box is developed with the following features: a blue main

function, the main beam function, a polka-dot motif, a rectangular function hole, a main function iron cover, ornament stickers, an additional function of a place to put candies, a pink additional color function, additional functional stripe motifs, and additional functional iron material.

Elly & Miftahul (2020) conducted research regarding aquascape product design using the QFD method. The objective of this research is to improve production by designing aquascape goods that take into account consumer preferences. Designing a three-in-one aquascape device that can do all three roles simultaneously is a top development objective. The initial purpose of a 57.6 W LED bulb, whose wattage is adjustable to the size of the aquarium, is to provide plant illumination in place of sunshine. Utilizing an 8" DC fan with a temperature range of 25–27°C serves as the second purpose, which also conserves energy. The third purpose is to decorate the space as a way to use novel product developments.

Antu & Djamalu (2018) developed an organic household waste shredder machine for fertilizer. In this study, a household-scale composting mechanism will be created so that each household's organic waste may be treated and put to immediate use. The composting machine's design accounts for the user's safety and comfort by altering the height of the general populace. Because moist waste materials are employed in the counting cylinder with a compost storage drawer, stainless steel was selected as the material to prevent corrosion and rust. For the convenience of usage, the engine drive utilizes a dynamo.

Research by Siregar & Siregar (2022) explains the development and design of the Srikaya mixer machine. In their research, the Srikaya jam mixer machine is designed which aims to help the process of making sugar apple jam, to be more effective and efficient. The stirrer that uses an electric motor drive and LPG stove heating was taken into consideration when designing this machine. Additionally, the cooking tube is built with a double jacket model so that it does not come into direct touch with the fire in order to avoid Srikaya jam from burning. According to the findings of the Srikaya jam mixer machine's performance test, it can produce 30 kg of jam in 8 hours.

Mohamad & Masruki (2021) study and simulate power and electrical voltage adjustment on CNC laser cutting for acrylic material. Designing a portable CNC laser cutting

machine is the study's goal. Performing a literature review, analyzing the requirements for creating machines, choosing and contrasting various alternative designs, conducting concept selection, designing laser modules and designing 3-axis motion systems, designing motor power, and simulating frames using the element method are all parts of the research methodology used for the design stage. The output of this research was a schematic for the control system of a CNC laser machine, the creation of a CNC laser machine prototype, and the parameter value of the performance test data of a CNC laser machine with a 3-axis CNC microcontroller based on an Arduino nano and a 5.5 Watt laser module with a maximum work area capacity of 200x100x10 mm.

Other researchers utilizing Quality Function Deployment (QFD) method are Bora et al. (2018), Hadrian & Sari (2018), Faizal et al. (2018), Suryaningrat et al. (2021), and Utami (2018). Bora et al. (2018) researched the product design of service using QFD in order to analyze the problem of customer satisfaction. The result revealed 6 services instrument that must be improved by the corporate. Faizal et al. (2017) researched the development of wall-shelf products by integrating QFD with Design for Manufacture and Assembly (DFMA). The aim of the research is to develop a wall-shelf product that is able to satisfy the customer's requirement. As a result, there are some attributes that are being focused on for improvements such as material quality, material endurance, material texture, material tenacity, product design, and product price. Whereas Hardian & Sari (2018), Suryaningrat et al. (2021), and Utami (2018) researched the development of product packaging utilizing the QFD method. The aim of the research is to increase customer retention due to a good and satisfied customer preference in packaging design. Hadrian & Sari (2018) research resulting packaging design that suits customer’s requirements with technical attributes. However, Suryaningrat et al. (2021) research findings that there are 4 important attributes such as strength, price, design, and safety. Moreover, Utami (2018) obtained that according to the customer's requirement, the wanted attributes include a unique design, eye-catchy color, reasonable price, size flexibility, and recyclability.

As a machine configuration, laser engraving technology is also required to identify its suitability. Research from Parthiban et al. (2019) found the best configuration parameter for CO2 laser cutting in Austenite stainless steel using the Grey Relay Analysis method. The

research found that cutting speed and gas pressure are the dominant parameters that affect the final result. Tatzel & Leóna (2019) once researched a predictive laser cutting interruption using the Logistic Regression method. Cutting interruptions during the laser process is undesirable for a number of reasons, including the increased material consumption and decreased productivity of the laser cutting equipment. It also may contaminate the laser cutting head, affecting a negative effect on the following operations and lengthening setup times. Results say that speed and focal position are factors that must be considered in order to reduce interruption in the laser cutting process. Other laser-cutting configuration research was conducted by Madića et al. (2017). The research is utilizing Preference Selection Index (PSI) method for the optimization of CO2 laser cutting of stainless steel. As a result, the method is cannot be useful when there is a numerous similar performance attribute parameters that close to the preferred parameter.

The utilization of laser cutting for wooden material was identified by several researchers including Putra (2019) and Samboro et al. (2017). The method used by Putra (2019) is by combining digital drawing and laser-cutting engraving methods. Resulting that the decorative wooden product in the shape of a dragon being developed by the combination of the two methods. Whereas, Samboro et al. (2017) focused on material efficiency for the wood waste industry using laser cutting technology. The research results that the optimization of laser cutting in processing wooden waste furniture is by configuring the trot speed, power, and speed settings.

Table 2.1.0.1 Inductive Literature Table

No	**Researcher**	**Year**	**Object**	**Review**			
				Machine Design	QFD	Laser Cutting	Others
1	Siswadi	2021	"Opak Jepit" Machine	✓	✓		

No	Researcher	Year	Object	Review			
				Machine Design	QFD	Laser Cutting	Others
2	Albertus	2020	Phone Charger		✓		
3	Li, Guo, & Cao	2018	Bamboo			✓	
4	Suartika, Alit, & Aprentari	2018	Corner Seat		✓		
5	Erlangga	2018	Oil Draining Machine	✓			✓
6	Chrisdio & Benedikta	2020	Table & Chair		✓		
7	Nurmianto, Wessiani, & Megawati	2018	Smooker Tools		✓		
8	Paulina & Ketut Purnawati	2018	Delivery Service		✓		
9	Maimunah, Lisha, & Atsari	2019	Brownies Packaging		✓		
10	Sanny & Prima	2018	Goat Dung Shredder	✓	✓		
11	Ginting, Batubara, & Widodo	2017	Multifuction Tissue Box		✓		
12	Elly & Miftahul	2020	Aquascape		✓		

No	Researcher	Year	Object	Review			
				Machine Design	QFD	Laser Cutting	Others
13	Antu & Djamalu	2018	Waste Shredder	✓			✓
14	Siregar & Siregar	2022	Srikaya Mixer Machine	✓			✓
15	Mohamad & Masruki	2021	CNC Laser Machine			✓	
16	Bora et al.	2018	Design of Service		✓		
17	Hardian & Sari	2018	Packaging Material		✓		
18	Faizal et al.	2017	Wall shelf		✓		
19	Suryaningrat et al.	2021	Material Packaging		✓		
20	Utami	2018	Packaging		✓		
21	Parthiban et al.	2019	Austenite stainless steel			✓	
22	Tatzel & Leóna	2019	Stainless steel			✓	
23	Madića et al.	2017	Stainless steel			✓	
24	Putra	2019	Wooden decorative			✓	
25	Samboro et al.	2017	Wooden waste furniture			✓	

No	Researcher	Year	Object	Review			
				Machine Design	QFD	Laser Cutting	Others
	Author	2022	Bamboo Holing Machine	✓	✓	✓	

2.2 Deductive Study

2.2.1 Bamboo

Bamboos are robust wooded area grasses that have greater than 1400 described species in one hundred fifteen genera. The most acquainted and beneficial are those with lignified stems that belong to the tribes Arundinarieae (temperate woody bamboos) and Bambuseae (tropical woody bamboos). There are roughly 1300 woody species that often play crucial roles in the ecology of their woodland habitats and have long been of economic significance to people (Kelchner, 2013).

As in other grasses, the internodal regions of the stem of the bamboo are typically hollow and the vascular bundles inside the move-section are scattered in the course of the stem instead of in a cylindrical association. As a grass family, bamboo has a monocotyledon stem wood, which means there is no dicotyledonous woody xylem for secondary growth (Loomis, 1967).

Bamboo plays a significant role in the economic and socio-cultural life of society in Asia, especially in South, East, and Southeast Asia. Bamboo is typically used for construction, and food supply, and is depicted frequently in arts, along with in bamboo paintings and bamboo work. Bamboo has a natural composite cloth with an excessive strength-to-weight ratio beneficial that is commonly utilized by people.

As a natural wood resource, bamboo has a high strength-to-weight building material ratio that makes bamboo a good material for construction as well as a solid decoration. In Japan, bamboo is commonly used as decorative and supplemental construction material. Several decorative entities are used in the Japanese architectural style such as fencing,

fountains, grates, and gutters (Bess, Moore, & Wein, 1987). Of its unique characteristic, bamboo is liked due to its strength and renewability. Its strength is made by the long bamboo fiber that reinforced its structure. However, the strength of the bamboo material is based on the bamboo's physical and chemical characteristics (Gaoa, et al., 2022).

However the cendani bamboo or known as fishpole bamboo is a type of 'running bamboo' and is native growth in China, especially in Fujian and Zhejiang (The Plant List, 2012). The fishpole bamboo can easily be recognized as its shape that has a slightly small internode and also a solid surface appearance. The fishpole bamboo is commonly utilized as an ornament and privacy hedges.

2.2.2 Product Design

Product design is the process of designing products that have optimal functionality, aesthetics, and user experience. Technically, the product design process involves various steps, such as identifying user needs, gathering information about markets and competitors, developing concepts, prototyping, and testing products. In the last five years, there have been various new technologies and trends that have influenced the product design process. One such trend is the use of data-driven design or data-driven design. In data-driven design, designers collect and analyze user data to understand user preferences, needs, and behavior. Thus, designers can design products that better suit user needs (Gibson, 2021).

Moreover, according to Ab Rahman (2019), the step for conceding the product design is divided into:

1. Research

The first stage in product design is to research the product to be designed. This research includes market analysis, understanding of user needs, and evaluation of existing similar products. In conducting this research, designers can use various technologies such as data analysis and online surveys.

2. Sketching and Prototyping

After having a sufficient understanding of the product to be designed, the designer will carry out the sketching process to produce a design concept. After that, the design concept will be

turned into a prototype. In this process, designers can use technologies such as 3D printing or CNC machining to make prototyping easier.

3. Testing and Evaluation

After having a prototype, the next stage is testing and evaluating the product. In this stage, the designer will test the product against internal users or teams. In this process, designers can use technology such as augmented reality or virtual reality to facilitate evaluation.

4. Production

After the product has successfully passed the testing and evaluation stage, the product will be mass-produced. In this process, the designer will coordinate with the production team to ensure that the product is produced according to the design that has been made. In this production process, designers can use technology such as the Internet of Things to monitor the production process in real time.

2.2.3 Participatory Design

According to Brandt & Messeter (2018), participatory design is a research approach that involves actively involving users or stakeholders in the design process to ensure that the resulting product meets their needs and expectations. It is a collaborative approach that engages users as co-designers, rather than simply as passive recipients of products or services. In the context of product design research, participatory design involves working with users to understand their needs, preferences, and usage patterns. This could include activities such as interviews, surveys, usability testing, and design workshops. By involving users in the design process, researchers can gain insights into user needs and preferences and can use this information to create products that better meet their needs.

Participatory design has several benefits, including:

1. Improved Product Quality

   By involving users in the design process, researchers can gain insights into user needs and preferences and can use this information to create products that better meet their needs.
2. Increased User Satisfaction

Participatory design can lead to products that are more user-friendly and intuitive, which can increase user satisfaction and loyalty.

3. Greater Stakeholder Buy-In

When stakeholders are involved in the design process, they are more likely to feel invested in the resulting product and are more likely to support its implementation.

2.2.4 Laser Cutting

Laser cutting is a technology of laser used to vaporize materials. Laser cutting is commonly used for industrial, manufacturing, and also for educational purposes (Thomas, 2013). The first laser cutting machine is produced in 1965 that is used to drill holes in diamond dies. Hilton (2007) said that the first technology of laser cutting adapt the laser-assisted oxygen jet cutting for metals that is found in 1967 in British. In early 1970, the laser technology to cut titanium for aerospace uses has been put into production and in the same period, because CO2 lasers were not strong enough to overcome the heat conductivity of metals at the time, they were modified for cutting non-metals like textiles.

The process of laser cutting is started with electrical discharges or lights within a confined container stimulating a lasing material, resulting in a laser beam. The beam is internally reflected by a partial mirror when the lasing material is stimulated until it obtains sufficient energy to exit as a stream of monochromatic coherent light. Coherent light is often sent to a lens, which concentrates the light at the work zone, using mirrors or fiber optics (TWI Global, 2014).

Moving material, hybrid, and flying optics systems are the three most common configurations of industrial laser cutting equipment. The manner the laser beam is moved across the material to be cut or treated is referred to as this. The axes of motion for all of them are usually referred to as the X and Y axis. The Z-axis is marked whether the cutting head may be controlled (Caristan, 2004).

A fixed cutting head is used in moving material lasers, which move the material below it. This approach maintains a consistent distance between the laser source and the workpiece, as well as a single location from which cutting effluent may be removed. Hybrid lasers have

a table that travels along one axis (typically the X-axis) while the head moves along a shorter axis (the Y-axis). In comparison to a flying optic machine, this results in a more consistent beam delivery route length and may allow for a simpler beam delivery system. Flying optics lasers have a stationary table and a cutting head (with a laser beam) that moves in both horizontal dimensions over the workpiece. Flying optics cutters maintain the workpiece steady throughout processing and don't always need to clamp the material. Because the moving mass is constant, the dynamics are unaffected by the workpiece's size (G.E. Mathis Company, 2019).

Its application, several types of laser cutters commonly used which is:

1. CO2 Laser Cutters

   CO2 laser cutters use a gas mixture of carbon dioxide, nitrogen, and helium to generate a laser beam that can cut through materials like wood, acrylic, and plastic. They are widely used in industries such as signage, textile, and packaging.
2. Fiber Laser Cutters

   Fiber laser cutters use a fiber-optic cable to deliver the laser beam, which is generated by a solid-state laser source. They are primarily used for cutting metal materials, such as steel and aluminum, and are widely used in the automotive and aerospace industries.
3. Diode Laser Cutters

   These cutters use a semiconductor diode to generate the laser beam, which is typically in the infrared range. They are used for cutting and marking materials like plastics, rubber, and textiles, and are popular in industries such as electronics and medical device manufacturing.
4. CO Laser Cutters

   CO laser cutters use a carbon monoxide gas mixture to generate the laser beam. They are primarily used for cutting and welding metals and are known for their high cutting speeds and energy efficiency.
5. UV Laser Cutters

   UV laser cutters use a short-wavelength ultraviolet laser beam to cut through materials like glass, ceramics, and sapphire. They are known for their high precision and accuracy and are widely used in industries such as microelectronics and photonics.

2.2.5 Machine Design

In general, machine design is concerned with the creation of functional mechanics and power sources. Designers, on the other hand, invariably specialize; they could focus on things like the design of engines or turbines or the functional components of cars, machines, or automation systems (Sabhadiya, 2020). There are three categories of machine design:

1. Adaptive Design

   The adaptive design is making use of fundamental design while adding minor adjustments to suit the requirements. This category is saving time for engineers rather than they should build a new product from the start.
2. Developmental Design

   The developmental design builds on preexisting ideas and technologies while incorporating fresh features and parts to produce something entirely new.
3. New Design

   The new and distinctive components and technologies that are being developed will produce unique inventions and it is categorized as New Design when engineers and designers create something wholly unique.

2.2.6 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a product design strategy that integrates customer wants for a product with technology or characteristics that are most important to create based on consumer preferences. The customer's voice begins the QFD process, which is followed by four activities: product planning, product design, process planning, and process control planning.

In QFD, a quality requirement represents a customer's needs, whereas a quality element represents technological elements. Customer expressions that are directly collected from data collected via consumer demand surveys for a product are known as quality requirements. The quality element, on the other hand, is a technical word for a criterion used to evaluate product quality (Hara, 2018).

2.2.7 House Of Quality (HOQ)

The House of Quality (HOQ) is a product planning matrix that demonstrates how consumer criteria are closely related to the strategies and techniques businesses might employ to meet those objectives. HOQ commonly becomes a primary tool in order to proceed with decision-making with Quality Function Deployment (QFD) method (Chrisdio & Benedikta, 2020).

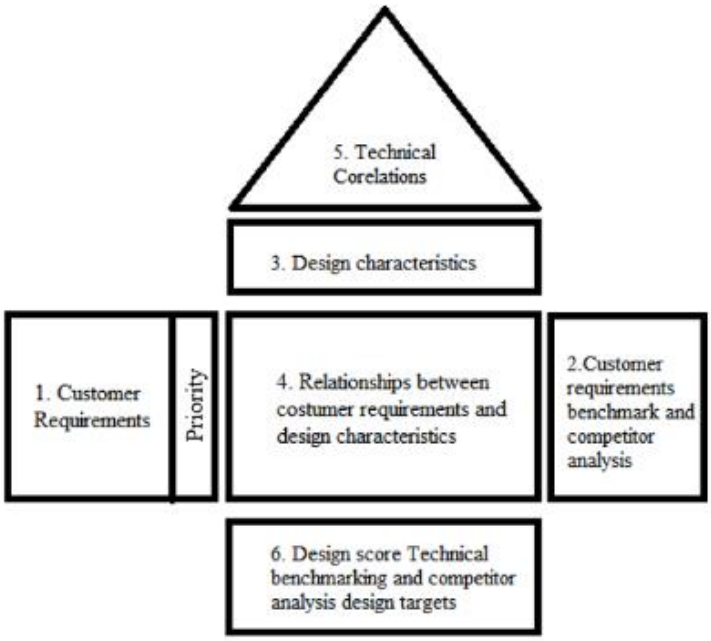


Figure 2.0.1 House of Quality

Accordingly, the HOQ has several parts that must be fulfilled such as:

1. Customer Requirements

   Consist of information retrieved demand from customer requirements. This part is including the voice of customers as an input to the house of quality.

2. Customer requirement benchmark

   This part is a component that converts the customer requirements in HOQ, to be a part of a plan of fulfillment.

3. Design characteristic

   This part is contributing to converting the voice of the customer to the voice of the developer. Or in the other hand, this part is answering about “how” the customer requirements are translated to be a design characteristic.

4. Relationship

   The relationship matrix is a correlation matrix of systematic correlation from customer requirements, benchmarks, and design characteristics.

5. Technical correlation

   The technical correlation matrix is a set of correlations and requirements of technical characteristics developed one with another.

6. Technical score

   The technical score matrix consists of a conclusion of the matrix that has developed in HOQ such as technical response priority, competitive technical benchmark, and technical target.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Object

The object of this research is the fishpole bamboo holing machine that will be used to do a perforation function to fishpole bamboo so the bamboo takes a shorter time to be produced into a finished product of a fishpole bamboo panel.

3.2 Research Subject

The subject criterion for this research is the owner/management of PT. Dekorasia Jayakarya and the outsourcing workers of the fishpole bamboo panel that is hired by PT. Dekorasia Jayakarya will be working as a product operator.

3.3 Research Methodology

3.5.1 Data Collection Method

The data collection is aimed to give the best alternative solution in order to solve the formulated problem. The method used is qualitative and the data required is quantitative data consisting of preference level determination to be able to obtain the desired configuration of the designed product.

There are ways to obtain the required data including:

1. Primary Data

Primary data is information that has been gathered directly from the outcomes of field observations. The primary data for this research is the data of users' requirements and the user matrix that will be used for product development. In this research, primary data is obtained from Focus Group Discussions (FGD) and interviews.

a. Focus Group Discussion (FGD)

The focus group discussion is aimed to be able to form of discussion about the needs, complaints, desires, points of view, and experiences desired by the workers and also assisted by the perspectives of experts.

b. Interview

The interview is asked to get additional information required regarding the product that will be developed. The interview will be conducted with the stakeholders such as the owner/ manager of PT. Dekorasia Jayakarya and not limited to outsourcing workers in PT. Dekorasia Jayakarya.

c. Closed Questionnaire

The closed questionnaire is spread in order to get the data of customer comparison between the developed product with the existing product with similar characteristics. The questionnaire will be given to the stakeholders involved in the research.

2. Secondary Data

The data used to supplement primary data are referred to as secondary data. Secondary data came from journal articles, literature reviews, and earlier research.

3.5.2 Research Method

The method implemented in this research is using Quality Function Deployment supported by a participatory design research approach. In participatory research, the beneficiaries are involved in the planning and execution of the study as well as in the interpretation and application of the research's findings.

3.4 Research Flow

The following is the research flowchart for this research:

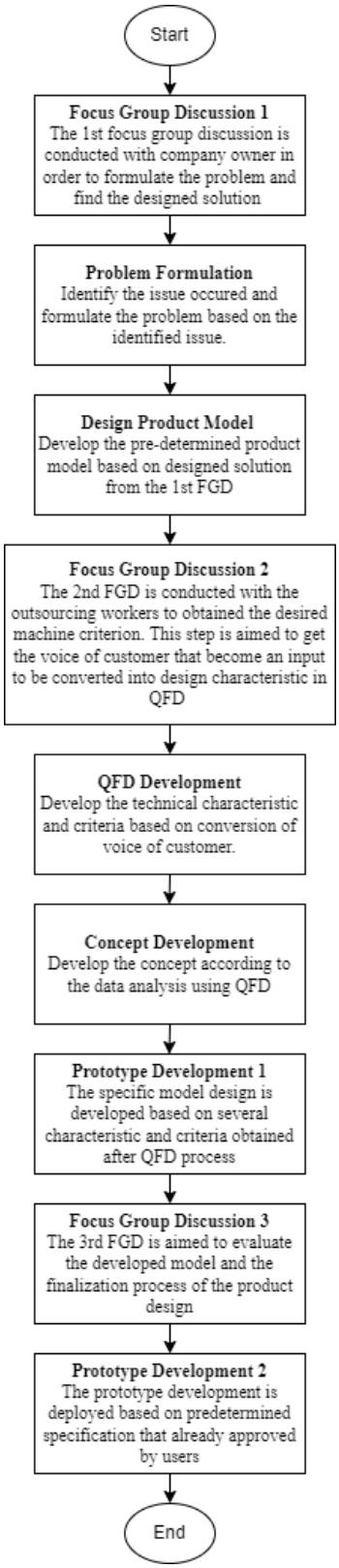


Figure 3.4.1 Flowchart Diagram

3.4.1 Focus Group Discussion 1

The first step in the research process at this point is the focus group discussion conducted in cooperation with UII and PT. Dekorasia Jayakarya. The 1st FGD is discussing the issue that was happening in several operation processes. The issue in the process of holing fishpole bamboo is one of the issues faced by the company. Moreover, that issue, several questions were asked including:

1. How severe is this problem for the whole process of production?
2. What does the temporary action do in order to reduce the problem's impact?

Moreover, the unstructured interview was also conducted in order to find the specific requirement and goals that are set by the company, including:

1. Are there any specific tools that are willing to be developed in order to reduce the operational issue?
2. By whom that this problem is mostly faced?

The meeting is attended by the owner of PT. Dekorasia Jayakarya, 4 lecturers and UII employees, and 5 students. By this meeting, the issue is raised and the problem is already identified. Furthermore, problem formulation will be generated as an action for the identified problem.

3.4.2 Problem Formulation

The problems determined at this stage were carried out after going through the interview steps, as well as the 1st FGD then formulated into several points. These problems will then become the basis for machine design in order to meet user needs.

3.4.3 Design Product Model

After getting the problem formulation from interviews and FGD 1, then the product design process was carried out. Provisional product design is carried out using design sketches with key attributes that can be visualized. At this stage, the specific attributes of the product being designed have not yet been determined.

3.4.4 Focus Group Discussion 2

The 2nd FGD is conducted aiming to evaluate the product designs that had been made. Phase 2 FGD aims to determine the product design attributes from the voice of customers (VOC) that will be designed which will then be processed with QFD. The questions asked in the 2nd FGD such as:

1. Are there any specific attributes that are willing to be developed for this product?
2. How about other attributes like durability, cost, safety, and easy operation?
3. In 1-5 how important for the following criterion for the product configuration?
4. The following is the concept design for the designed machine. Do you have any suggestions for the model of the machine?

In the 2nd FGD, the participant for this process is several outsource workers that are 9 operators and 1 owner of the firm. The outsourcing firm party might be able to give their perspective and ideas for the developed product further.

3.4.4 QFD Development

From the result of the 2nd FGD, the insights, and requirements that are told by the firm will be further processed as input for the QFD. In this phase, it is still possible if any additional data to be collected in order to complete the analysis process. The input includes the specific attribute desired as well as its important rating. Moreover, the input will proceed using the 2 phases of Quality Function Deployment (QFD) in order to find the specific model characteristic and specification for the product development.

3.4.5 Concept Development

According to the result and data analysis from QFD development, the data obtained from QFD is transformed into a design concept idea that is able to conceptualize the data into a visual concept of a product. This process will be an input for the prototype development that will be developed by implementing concept design into prototype design.

3.4.6 Prototype Development 1

After obtaining specific design attributes from the HOQ process of QFD, the product prototype development is designed. The product prototype design is carried out using a 3-dimensional model so that it can be visualized from various directions. In designing product

designs, the attributes or features needed for the output from the previous process have been determined so that it can make it easier to make 3D designs.

3.4.7 Focus Group Discussion 3

The product designs that have successfully completed the QFD stage will be identified at this point. As a result, the third stage of the FGD is a discussion on the design that the FGD participants implemented and it will be evaluating the product that has been made. The final design will be decided upon if more ideas are made in relation to the finished product.

3.4.8 Prototype Development 2

The prototype is developed from the 3D design that has been made and by the further discussion of the 3rd FGD. Thus, the development of a final design is in accordance with the parameter, user requirements, and user preferences.

CHAPTER IV

DATA COLLECTING AND PROCESSING

4.1 Data Collecting

The data-collecting process aims to obtain the data for the machine development process. The research is using a participatory method that involves the participant from the specified working environment. Problem identification, decision-making, problem-solving techniques, and assessment include all participants directly. However, the data collection will be obtained by FGD, questionnaire, and interview.

4.1.1 Problem Founding

The problem founding is conducted by direct and indirect observation. In direct observation, the problem is obtained on the issue that is raised by the company owner. The issue raised by the company was obtained from the FGD 1 process that lead to several issues faced by the company including:

Table 4.1.1 Overall Issue

No	Product Line	Issue
1	Bamboo Panel	The process of bamboo panel cleavage is time-consuming and less efficient.
2	Bamboo Screen	The process of bamboo perforation and assembly is time and cost-consuming since it uses subcontracting employees.
3	Rattan Stick	The process of rattan stick bending requires big resources and is time-consuming.

Thus, the issue faced by the company is close to the manufacturing productivity as well as the production cost. Especially for the Bamboo Cendani Screen product, the company is subcontracting for the production which makes them have less control over the production process.

However, direct observation is held in order to understand the real-time condition, especially the production process of the Bamboo Cendani Screen product.

The funding from the direct observation is that the process is commonly still utilizing manpower on its process. The process includes drying, cleaning, cutting, holing, and assembly.

4.1.2 Requirement Identification

The research is aiming to be able to initiate the improvement of the production process of the Bamboo Cendani Screen product in PT. Dekorasia Jayakarya. Accordingly, literature study, interviews, and direct observation are conducted in order to compile requirements from company owners, subcontractors, and stakeholders. The interview is asked of the company owner, and 8 subcontractors to obtain the product requirement that might be able to improve the issue faced by the company in the production process.

Therefore, the stakeholder's requirement will become the basis of the machine development. According to the interview and FGD 1, there is a recapitulation of the issue and requirements stated by several stakeholders:

Table 4.1.2 Issue from FGD 1

No	Issues	Ideas
1	High man-powered production process.	Development of machines that are able to ease or automate the production process.
2	High resource requirements due to defects.	Machine features that are able to assist in precision.
3	Material crack due to physical pressure.	CO2 laser technology utilization.
4	Quality issue due to man-powered production in the perforation process.	Automated machine system.
5	Backpain for the workers.	Adjustable height.

Moreover, the result obtained from the issue recapitulation is becoming a basis of the machine development for the perforation machine.

4.1.3 Obtaining the Voice of Customers

The process of obtaining Voice of Customers (VOC) is aiming to obtain the voice of customers with the stakeholders that are close to the production process and management of the Bamboo Cendani Screen product. The voice of customers obtained is furtherly considered as the basic development of the Bamboo Cendani Perforation Machine. In close with the utilization of participatory analysis research, the data collection is performed through direct interviews.

The direct interview is conducted with 10 respondents including 9 sub-contracted workers and the owner of Dekorasia. The interview was conducted in order to find out the

Voice of Customers (VOC) for the perforation machine. The questions asked are closely related to the interviewee's opinion of the preferred criteria for the Bamboo Cendani Perforation Machine. The question asked for the interview is "What are the criteria preferred to be implemented in the development of a Bamboo Cendani Perforation Machine? (Example: durable, progressive, low cost)".

Thus, the result obtained from the VOC for the criteria preferred in the development of the Bamboo Cendani Perforation Machine is as follows:

Table 4.1.3 Voice of Customers

No	Customer Need	Voting Number	Percentage
1	Faster the work	5	12%
2	Good performance	5	12%
3	Progressive	5	12%
4	Durable	4	10%
5	Safe to use	4	10%
6	Easy maintenance	3	10%
7	Strong	3	7%
8	Easy to operate	3	7%
9	Good material quality	2	5%
10	Easy use	2	5%
11	Compact	1	2%
12	Low maintenance cost	1	2%
13	Affordable	1	2%
14	Low cost	1	2%

Furthermore, obtained data will be further converted to obtaining attribute requirements that are grouped by the customer's need based on common functional similarity. The attributes requirements will furtherly be used as a development basis for the perforation machine. The result of attributes requirements is found as follows:

Table 4.1.4 Group of Customer Requirements

No	Customer Need	Attribute
1	Faster the work	Progressive
2	Good performance	Progressive
3	Progressive	Progressive
4	Durable	Durable
5	Safe to use	Safe
6	Easy maintenance	Ease of use
7	Strong	Durable
8	Easy to operate	Ease of use
9	Good material quality	Durable
10	Easy use	Ease
11	Compactness	Compact
12	Low maintenance cost	Low cost
13	Cheap	Low cost
14	Low cost	Low cost

Accordingly, the summary of attributes obtained from the voice of customers from the table above was as:

Table 4.1.5 Summary of Attributes

No	Attribute
1	Progressive
2	Durable
3	Safe
4	Ease of use
5	Compact
6	Low cost

4.2 Data Analysis

4.2.1 House of Quality (HOQ)

1. Important Rating

The development of a product based on the customer requirements attributes obtained from Voice of Customers (VOC) needs to consider the important rating. Important rating (IR) is the degree of importance arranged according to the importance level of attributes for the development of the Bamboo Cendani Perforation Machine. The scale that is used for the development of customer requirements attributes based on the importance level includes:

- 5 score for the necessary attribute
- 4 score for the important attribute
- 3 score for the neutral attribute
- 2 score for not too important
- 1 score for not important

Moreover, the following is the result obtained from the important rating analysis:

- Important rating calculation for Progressive attribute

Table 4.2.1 Important Rating for Progressive

Progressive			
Description	Score	Frequency	Result
Necessary	5	5	25
Important	4	2	8
Neutral	3	3	9
Not too important	2	0	0
Not important	1	0	0
Total		**10**	**42**
Important rating		**4.2**	

- Important rating calculation for Durable attribute

Table 4.2.2 Important Rating for Durable

Durable			
Description	Score	Frequency	Result
Necessary	5	1	5
Important	4	3	12
Neutral	3	5	15
Not too important	2	1	2
Not important	1	0	0
Total		**10**	**34**
Important rating		**3.4**	

- Important rating calculation for Safe attribute

Table 4.2.3 Important Rating for Safe

Safe			
Description	Score	Frequency	Result
Necessary	5	2	10
Important	4	4	16
Neutral	3	4	12
Not too important	2	0	0
Not important	1	0	0
Total		**10**	**38**
Important rating		**3.8**	

- Important rating calculation for Ease of use attribute

Table 4.2.4 Important Rating for Ease of Use

Ease of use			
Description	Score	Frequency	Result

Necessary	5	3	15
Important	4	4	16
Neutral	3	2	6
Not too important	2	1	0
Not important	1	0	0
Total		**10**	**37**
Important rating		**3.7**	

- Important rating calculation for Compact attribute

Table 4.2.5 Important Rating for Compact

Compact			
Description	Score	Frequency	Result
Necessary	5	0	0
Important	4	2	8
Neutral	3	6	18
Not too important	2	1	2
Not important	1	1	0
Total		**10**	**28**
Important rating		**2.8**	

- Important rating calculation for Low-Cost attribute

Table 4.2.6 Important Rating for Low Cost

Low Cost			
Description	Score	Frequency	Result
Necessary	5	1	5
Important	4	2	8
Neutral	3	5	15
Not too important	2	1	2

Not important	1	1	0
Total		**10**	**30**
Important rating		**3.0**	

In summary, these are the important ratings obtained from the scoring of attributes based on the voice of customers:

Table 4.2.7 Summary Important Rating

Attribute	Important Rating
Progressive	4.2
Durable	3.4
Safe	3.8
Ease of use	3.7
Compact	2.8
Low cost	3.0

2. Technical Requirements

The technical requirements are obtained from the customers' requirements that are translated into technical characteristics from the customer requirements. In order to better define a general design, one of the crucial stages in the product planning matrix is translating customer requirements into technical terminology (Widodo, 2005). Each technological criterion has a few characteristics that can be linked to a number of identifying features of the intended product. Each customer requirement is converted into a set of technical requirements that can be measured and have certain properties.

Therefore, the following is the technical characteristic obtained from the translation of customer requirements:

Table 4.2.8 Technical Requirement

No	Customer Requirement	Technical Requirement
1	Progressive	CNC laser technology utilization Having an integration-friendly feature
2	Durable	Capable material Good machine strength
3	Safe	Have human safety features S&OP providence
4	Ease of use	Built with ergonomic feature Manual operation instruction
5	Compact	Space saving
6	Low cost	Low maintenance cost Low usage cost

3. Target Determination

The design aims to create a device for perforating holes in fishpole bamboo. In order to establish quantifiable goals for the needs to be met, a description of the technical requirements of the customer's demands is carried out at this stage. The target determination is a process of getting the measurable technical requirement which is able to be implemented in order to reach the intended technical requirement. The technical target for machine development is listed below:

Table 4.2.9 Specification Target

Technical Requirements	Target
CNC laser technology utilization	CNC CO2 Laser
Having an integration-friendly feature	Detachable V-shape Gantry Body, 70-,100 cm leg rooms, 60-80 cm width room
Capable material	Aluminum body frame
Good machine strength	Frame joint to the gantry body frame, T-slot fastener
Have human safety features	Cover hood with 90% sight reduction, machine cover
S&OP providence	Development of machine S&OP
Built with ergonomic feature	Adjustable height, 75 cm – 100 cm
Make space-saving design	Length = 150cm, width = 80cm, height = 75 – 100 cm
Manual instruction providence	Provide the machine with operation manual instruction
Low maintenance cost	Using ±35 part model
Low usage cost	3.5 kWh power consumption

4. Correlation of Customers and Technical Requirements

The further process after obtaining customer requirements and determining technical requirements is to determine the correlation between customers and technical requirements. The determination of the correlation between technical and customer requirements is by giving a degree of scoring between aspects correlated. The degree consists of strong (9 scores), medium (3 scores), weak (1 score), and none (0 scores). A strong degree is obtained if the technical requirement is a direct interpretation of customers' requirements. The medium degree is obtained from the technical requirement that is not a direct interpretation of customers' requirements but has a strong correlation. A weak degree is obtained if the

technical requirement is not a direct interpretation and has a weak correlation between customers and technical requirements. None is obtained if there is no correlation between technical and customer requirements.

Accordingly, the correlation matrix of customer and technical requirement is as follows 4.2.1 figure.

Row Number	Max Relationship Value in Row	Relative Weight	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	CNC Laser Technology Utilization	Having Integration-Friendly Feature	Capable Material	Good Machine Strength	Have Human Safety Features	S&OP Providence	Built with Ergonomic Feature	Manual Instruction Providence	Make Space Saving Design	Low Maintenance Cost	Low Usage Cost
1	9	20.10	Progressive	9	9									1
2	9	16.27	Durable			9	9							
3	9	18.18	Safe					9	9	3	9			
4	9	17.70	Ease of Use	1	1			3	9	9	9			
5	9	13.40	Compact				1			3		9		
6	9	14.35	Low Cost	3		3							9	9

Figure 4.2.1 Correlation Requirement

5. Calculating Requirement Weight

A method for gathering data and levels in product design development is to calculate requirement weights. The matrix values of the connection between customer requirements and technical characteristics are multiplied and added to produce requirement weight values.

The value of weight requirements is obtained through the equation:

$$Requirement\ Weight = Important\ Rating\ (IR) \times Relative\ Weight$$

Thus, the obtained result for requirement weight calculation is as follows:

Row Number	Important Rating	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	CNC Laser Technology Utilization	Having Integration-Friendly Feature	Capable Material	Good Machine Strength	Have Human Safety Features	S&OP Providence	Built with Ergonomic Feature	Manual Instruction Providence	Make Space Saving Design	Low Maintenance Cost	Low Usage Cost
1	20.10	Progressive	9	9									1
2	16.27	Durable			9	9							
3	18.18	Safe					9	9	3	9			
4	17.70	Ease of Use	1	1			3	9	9	9			
5	13.40	Compact				1			3		9		
6	14.35	Low Cost	3		3							9	9
		Target or Limit Value	CNC CO2 Laser	Detachable V-shape Gantry Body, 70-,100 cm leg rooms, 60-80 cm width room	Aluminum Main Body Frame	Frame joint to the gantry body frame, T-slot fastener	Cover hood with 90% sight reduction, machine cover	Machine S&OP Development	Adjustable Height, 75 cm - 100 cm	Provice Machine with Manual Instruction	Length = 150cm, width = 80cm, height = 75 — 100 cm	Using ±35 part model	3.5 kWh power consumption
		Requirement Weight	241.6	198.6	189.5	159.6	216.7	323	254.1	323	120.6	129.2	149.3

Figure 4.2.2 Correlation Requirement Weight

6. Correlation Matrix

The correlation matrix is a matrix that helps to identify the positive or negative relationships between customer requirements and the design and technical requirements that will meet those requirements. It is called the "roof" because it sits at the top of the "house of quality" diagram. The correlation matrix is important because it helps to prioritize the technical requirements that are most important to meeting customer needs. By identifying the strongest correlations between customer needs and technical requirements, the design team can focus their efforts on optimizing those requirements to meet customer expectations (Kanagaraj, 2018).

Correspondingly, the correlation matrix implemented in the development of the Bamboo Cendani Perforation Machine is as follows:

	Column Number	1	2	3	4	5	6	7	8	9	10	11
Row Number	**Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")**	CNC Laser Technology Utilization	Having Integration-Friendly Feature	Capable Material	Good Machine Strength	Have Human Safety Features	S&OP Providence	Built with Ergonomic Feature	Manual Instruction Providence	Make Space Saving Design	Low Maintenance Cost	Low Usage Cost
1	CNC Laser Technology Utilization											
2	Having Integration-Friendly Feature	+										
3	Capable Material		+									
4	Good Machine Strength		+	+								
5	Have Human Safety Features			+	+							
6	S&OP Providence					+						
7	Built with Ergonomic Feature					+						
8	Manual Instruction Providence					+	+					
9	Make Space Saving Design		-									
10	Low Maintenance Cost	-	-						+			
11	Low Usage Cost	-									+	

Figure 4.2.3 Correlation Matrix

Accordingly, the technical characteristic correlation for the development is summarized as :

1. The integration-friendly features have a **positive** correlation with laser technology utilization.
2. Capable materials have a **positive** correlation with integration-friendly features.
3. Machine strength has a **positive** correlation with integration-friendly features and capable material.
4. Human safety factors have a **positive** correlation with capable material and mechanical strength.
5. S&OP has a **positive** correlation with human safety factors.
6. Ergonomic features have a **positive** correlation with human safety factors.
7. Manual instruction has a **positive** correlation with human safety factors and S&OP.
8. Space-saving design has a **negative** correlation with integration-friendly features.
9. Low maintenance cost has a **negative** correlation with laser technology utilization but has a positive correlation with manual operation instruction.
10. Low usage cost has a **negative** correlation with laser technology utilization but has a positive correlation with low maintenance cost.

7. Direction Improvement

Direction improvement in QFD is the process of identifying key customer requirements and translating them into technical specifications that can be met by product design. The direction improvement is also determining “if the requirement is intended to be maximized (▲), minimize (▼), or to hit a particular target (x). The improvement matrix for the development of the Bamboo Cendani Perforation Machine is as follows:

Minimize (▼), Maximize (▲), or Target (x)	x	▲	X	▲	▲	x	x	x	x	▲	▲
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	CNC Laser Technology Utilization	Having Integration-Friendly Feature	Capable Material	Good Machine Strength	Have Human Safety Features	S&OP Providence	Built with Ergonomic Feature	Manual Instruction Providence	Make Space Saving Design	Low Maintenance Cost	Low Usage Cost

Figure 4.2.4 Improvement Direction

According to the improvement direction matrix 4.2.4, the result of determining the direction improvement is as follows:

1. Laser technology utilization is intended to be targeted.
2. Integration-friendly features are intended to be maximized.
3. Capable material is intended to be targeted.
4. Machine strength is intended to be maximized.
5. A human safety factor is intended to be maximized.
6. S&OP is intended to be targeted.
7. The ergonomic feature is intended to be targeted.
8. A manual instruction is intended to be targeted.
9. Space-saving design is intended to be targeted.
10. Low maintenance cost is intended to be maximized.
11. Low usage cost is intended to be targeted.

8. Benchmarking

Benchmarking is a process of comparing the specification between the existing product with similar characteristics with the developed product which is the Bamboo Cendani Perforation Machine in order to obtain the specified design and specification of the developed product. This process is also useful in order to obtain the Customer Competitive Evaluation (CCE) that furtherly will be evaluated.

The existing product that will be benchmarked is the perforation machine that is being mostly used by the manufacturer in order to perform the process of perforation for fishpole bamboo.

Figure 4.2.5 Drill Machine for Bamboo Perforation

Therefore, the following table is the matrix benchmarking between the traditional perforation machine and Bamboo Cendani Perforation Machine.

Table 4.2.10 Benchmark on Metric

No	Customer Needs	IR	Metric	Unit	Current Perforation Machine	Bamboo Cendani Perforation Machine
1	1	20.10	Perforation Tool	Type	Drilling Machine	CNC CO2 Laser Machine
2	1	20.10	Body Component	Type	Drill Machine Body Component	Detachable V-shape Gantry Body

No	Customer Needs	IR	Metric	Unit	Current Perforation Machine	Bamboo Cendani Perforation Machine
3	1	20.10	Space Rooms	cm	1 cm bed space, 20 cm legroom	70-100 cm leg rooms, 60-80 cm width room
4	2	16.27	Material Component	Type	Wooden Material	Aluminum
5	2	16.27	Joint Configuration	Type	Wooden Joint	Frame joint to the gantry body frame, T-slot fastener
6	3	18.18	Safety Factors	Type	-	Cover hood with 90% sight reduction, machine cover
7	3	18.18	S&OP	List	-	Machine SOP
8	4	17.70	Ergonomy	List	-	75-100 cm height adjustment
9	4	17.70	Manual Instruction	List	-	Machine Manual
10	5	13.40	Body Dimension	cm	H = 50 cm, L= 120 cm, W = 30cm	H = 110-140 cm, L= 150 cm, W= 80 cm
11	6	14.35	Component Parts	Amount	±30 part model	±35 part model
12	6	14.35	Power Consumption	Kilo Watt/hour	0.65	3.5

Besides, the following is the intended specification of the Bamboo Cendani Perforation Machine.

Table 4.2.11 Set Final Specification

No	Metric	Unit	Set Value
1	Perforation Tool	Type	80 Watt CNC CO2 Laser Machine
2	Body Component	Type	Detachable V-shape Gantry Body
3	Space Rooms	cm	70-100 cm height rooms, 60-80 cm width room
4	Material Component	Type	Aluminum
5	Joint Configuration	Type	Frame joint to the gantry body frame, T-slot fastener
6	Safety Factors	Type	Cover Hood with 90% Sight Reduction, Machine Cover
7	S&OP	List	Machine Use
8	Ergonomy	List	Adjustable height, 75 cm – 100 cm
9	Manual Instruction	List	Provide the machine with

No	Metric	Unit	Set Value
			operation manual instruction
10	Body Dimension	cm	Length = 150cm, width = 80cm, height = 75 – 100 cm
11	Component Parts	Amount	±35 part model
12	Power Consumption	kWh	3.5

9. Customer Competitive Evaluation

The following stage is to compare the product being created with already existing products with similar process characteristics. To determine how well a product has met customer requirements relative to rival goods, customer competitive evaluation is used. The evaluation commonly takes focus on the benchmark on metric from Table 4.2.11 between the current existing perforation machine and with Bamboo Cendani Perforation Machine. This step is carried out by spreading the close questionnaire to 10 stakeholders which examines attributes based on a 1 to 5 scale with detail:

Table 4.2.12 Customer Satisfaction Attribute

Attribute	Scale	Attribute	Scale
Progressive	1. So not progressive 2. Not progressive 3. Quite progressive 4. Progressive	Durable	1. So not durable 2. Not durable 3. Quite durable 4. Durable

	5. Very progressive		5. Very durable
Safe	1. So not safe 2. Not safe 3. Quite safe 4. Safe 5. Very Safe	Compact	1. So not compact 2. Not compact 3. Quite compact 4. Compact 5. Very compact
Low Cost	1. So expensive 2. Expensive 3. Quite affordable 4. Affordable 6. Very affordable		

The following table is the result of a closed questionnaire for the product that already exists with a similar process characteristic.

Table 4.2.13 Questionnaire Result for Existing Product

No	Attribute	Scoring					Total
		1	2	3	4	5	
1	Progressive	1	5	4	0	0	10
2	Durable	1	7	1	1	1	10
3	Safe	2	4	2	2	0	10
4	Compact	2	2	4	2	0	10

5	Low Cost	0	2	3	3	2	10

As a comparison, the following table is the competitive evaluation result for the developed product of the Bamboo Cendani Perforation Machine.

Table 4.2.14 Questionnaire Result for Developed Product

No	Attribute	Scoring					Total
		1	2	3	4	5	
1	Progressive	0	1	2	4	3	10
2	Durable	0	2	3	3	2	10
3	Safe	0	1	3	2	4	10
4	Compact	1	3	5	1	0	10
5	Low Cost	1	4	4	1	0	10

To be able to compare, the attributes of customers' requirement are directly compared for the existing product and the designed product. Then, the attributes score will be divided into total voice in order to obtain the value of Customer Competitive Evaluation (CCE).

The scoring comparison for progressive attributes:

Table 4.2.15 CCE for Progressive Attribute

Progressive					
Scoring	Score	Developed Product	Total	Existing Product	Total
So not progressive	1	0	0	1	1
Not progressive	2	1	2	5	10
Quite progressive	3	2	6	4	12
Progressive	4	4	16	0	0
Very progressive	5	3	15	0	0

Total Score		39		23
CCE	3.9		2.3	

The scoring comparison for durable attributes:

Table 4.2.16 CCE for Durable Attribute

Durable					
Scoring	Score	Developed Product	Total	Existing Product	Total
So not durable	1	0	0	1	1
Not durable	2	2	4	7	14
Quite durable	3	3	9	1	3
Durable	4	3	12	1	4
Very durable	5	2	10	1	5
Total Score			35		27
CCE		3.5		2.7	

The scoring comparison for safe attributes:

Table 4.2.17 CCE for Safe Attribute

Safe					
Scoring	Score	Developed Product	Total	Existing Product	Total
So not safe	1	0	0	2	2
Not safe	2	1	2	4	8
Quite safe	3	3	9	2	6
Safe	4	2	8	2	8
Very Safe	5	4	20	0	0
Total Score			39		24
CCE		3.9		2.4	

The scoring comparison for compact attributes:

Table 4.2.18 CCE for Compact Attribute

Compact					
Scoring	Score	Developed Product	Total	Existing Product	Total
So not compact	1	1	1	2	2
Not compact	2	3	6	2	4
Quite compact	3	5	15	4	12
Compact	4	1	4	2	8
Very compact	5	0	0	0	0
Total Score			25		28
CCE		2.5		2.8	

The scoring comparison for low-cost attributes:

Table 4.2.19 CCE for Low-Cost Attribute

Low Cost					
Scoring	Score	Developed Product	Total	Existing Product	Total
So expensive	1	1	1	0	0
Expensive	2	4	8	2	4
Quite affordable	3	4	12	3	9
Affordable	4	1	8	3	12
Very affordable	5	0	0	2	10
Total Score			28		35
CCE		2.8		3.5	

To summarize, Table 4.2.21 is containing the comparison of every attribute as well as its CCE based on the previous result and calculation.

Table 4.2.20 CCE Summary

No	Attribute	Current Perforation Machine	Bamboo Cendani Perforation Machine
1	Progressive	2.3	3.9
2	Durable	2.7	3.5
3	Safe	2.4	3.5
4	Ease of Use	3.2	3.0
5	Compact	2.8	2.5
6	Low Cost	3.5	2.8

10. Goal Determination

The goal is the satisfaction value that must be gained for the upcoming product. Using a 1 to 5 scale, the value of customer satisfaction is determined. According to Cohen (1995), The performance goal is normally expressed in the same numerical scale as the performance level. In other word, the goal is determined from the average score of CCE for every distinct product from customers' requirement attribute. Moreover, the score of the goal from a single attribute of customer's need listed in Table 4.2.21.

Table 4.2.21 Goal Determination

Attributes	Goal Score
Progressive	3.1
Durable	3.1
Safe	2.95
Ease of Use	3.1
Compact	2.65
Low Cost	3.15

11. Determining Sales Point

A sales attribute with a high perceived selling worth is the sales point. Sales point analysis is done to determine how to increase the product's worth based on consumer needs, which will increase its selling power. To calculate the point value for each transaction of each consumer's requirements in the product being created using the scale of 1, 1.2, and 1.3 (Cohen, 1995).

Table 4.2.22 Sales Point Scale

Sales Point	Description
1	There is no sales point
1.2	Medium sales point
1.5	Strong sales point

The following justifies how the revenue point group was chosen:

1. A customer requirements attribute with an Importance Rating (IR) of 1 has poor selling power. This attribute also has a sales point value of 1.

2. A sales point number of 1.2 indicates that the customer requirements characteristic has a middle level of selling strength with an Importance Rating (IR) of 2 to 3.

3. A customer requirements characteristic with an Importance Rating (IR) > 3 and a sales point value of 1.5 can have strong selling potential.

Therefore, the sales point determination of the Bamboo Cendani Perforation Machine is as the following table

Table 4.2.23 Sales Point

No	Attribute	IR	Sales Point
1	Progressive	4.2	1.5
2	Durable	3.4	1.5

3	Safe	3.8	1.5
4	Compact	2.8	1.2
5	Low Cost	3.0	1.2

12. Improvement Ratio Calculation

The improvement ratio is a scale to measure a performance conducted in order to build product quality based on desired customer requirements (Cohen, 1995). The calculation of the improvement ratio is obtained by performing the formula:

$$Improvement\ Ratio = \frac{Goal}{Customer\ Satisfaction\ Performance}$$

Whereas the category that is commonly used in order to group the result of improvement ratio is grouped as the following table

Table 4.2.24 Improvement Ratio Scale

Improvement Ratio	Description
< 1	Not necessarily improved
1 – 1.5	Medium improvement
> 1.5	Overall improvement

Therefore, the result of the calculation of the improvement ratio from every attribute of customers' requirements is summarized in the below table:

Table 4.2.25 Improvement Ratio

Attribute	**Improvement Ratio**
Progressive	0.79
Durable	0.89
Safe	0.84
Compact	1.06
Low cost	1.13

13. Row Weight Calculation

The product development attributes that must exist because the components or parts contained in it are quite thorough are calculated using the row height. This implies that the importance increases as the attribute number increases. The calculation of row weight is performed using the following formula (Cohen, 1995):

$$Row\ Weight = Customer\ Satisfaction\ Performance \times Improvement\ Ratio \times Sales\ Point$$

The following table is the calculation result of the row weight calculation:

Table 4.2.26 Row Weight

Attribute	**Row Weight**
Progressive	4.65
Durable	4.65
Safe	4.425
Compact	2.65
Low cost	3.78

14. Action Determination

The next step needed to continue the HOQ process is to determine the action on the results of the HOQ analysis. The following Table 4.2.27 is including the specific action characteristics that are probably able to be taken in order to respond with strategic analysis.

Table 4.2.27 Action Description

Category	Action
A	Since the product under development lags far behind its competitors, product development can analyze the performance of those competitors and adapt it to the product under development.

B	Evaluation and idea creation are required because, in the eyes of users, the performance of competing products is preferable.
C	Product growth maintains product excellence.

According to the calculation of several attributes in a few performance indicators, it can be obtained several indicators that be able to be taken as decision-making for action that need to be taken in order to respond to competitors' positions. For that reason, the following Table 4.2.28 is several category and action that is taken in order to compete with the existing perforation machine.

Table 4.2.28 Determined Action

Attribute	Current Perforation Machine	Bamboo Cendani Perforation Machine	Action
Progressive	2.3	3.9	C
Durable	2.7	3.5	C
Safe	2.4	3.5	C
Compact	2.8	2.5	B
Low Cost	3.5	2.8	B

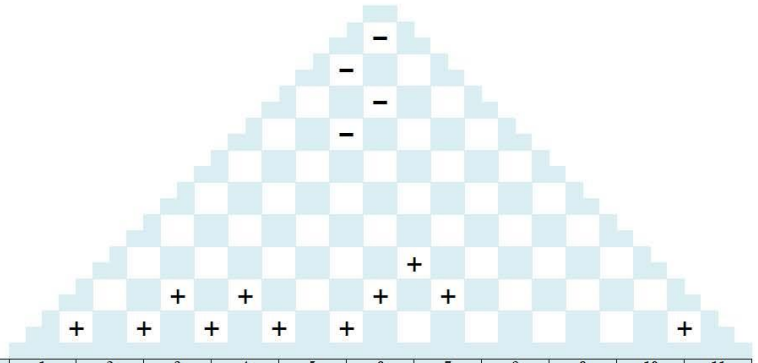
15. Design of House of Quality (HOQ)

The final design of House of Quality must be containing six part of its whole house which is the customer requirements, competitor analysis, technical characteristic, relationship of customer requirement and technical characteristic, technical correlation, and technical and competitor benchmarking analysis. The final picture of the designed Bamboo Cendani Perforation Machine with HOQ is in Figure 4.2.6.

Correlations	
Positive	+
Negative	−
No Correlation	0

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Column #				1	2	3	4	5	6	7	8	9	10	11	Customer Competitive Assesment						
			Direction of Improvement	◇	▲	◇	▲	▲	◇	◇	◇	◇	▲	▲							
Row #	Relative Weight	Customer Importance (1-5)	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	CNC Laser Technology Utilization	Having Integration Friendly Feature	Capable Material	Good Machine Strength	Have a Human Safety Features	S&OP Providence	Built with Ergonomic Feature	Manual Instruction Providence	Make Space Saving Design	Low Maintenance Cost	Low Usage Cost	Bamboo Cendani Perforation Machine	Existing Perforation Machine	Goal	Sales Point	Improvement Ratio	Row Weight	Action
1	20%	4.2	9	Progressive	●	●									▽	3.9	2.3	3.1	1.5	0.79	4.65	C
2	16%	3.4	9	Durable			●	●								3.5	2.7	3.1	1.5	0.89	4.65	C
3	18%	3.8	9	Safe					●	●	○	●				3.5	2.4	2.95	1.5	0.84	4.425	C
4	18%	3.7	9	Ease of Use	▽	▽			○	●	●	●				-	-	-	-	-	-	-
5	13%	2.8	9	Compact				▽			○		●			2.5	2.8	2.65	1	1.06	2.65	B
6	14%	3	9	Low Cost	○		○							●	●	2.8	3.5	3.15	1.2	1.13	3.78	B
				Product Targets	CNC CO2 Laser	Detachable V-shape Gantry Body, 70..100 cm leg rooms, 60-80 cm width room	Alumunium Main Body Frame	Frame joint to gantry body frame, T-slot fastener	Cover Hood, Safety Design	Cover hood with 90% sight reduction, machine cover	Adjustable Height, 75 cm - 100 cm	Provice Machine with Manual Instruction	Length = 150cm, width = 80cm, height = 75 – 100 cm	Using ±35 part model	3.5 kWh power consumption						
				Max Relationship	9	9	9	9	9	9	9	9	9	9	9							
				Technical Importance Rating	241.63	198.56	189.47	159.81	216.75	322.97	254.07	322.97	120.57	129.19	149.28							
				Relative Weight	10%	9%	8%	7%	9%	14%	11%	14%	5%	6%	6%							

Figure 4.2.6 House of Quality

4.2.2 Part Deployment Matrix

The level 2 Quality Function Deployment is named part deployment. The second level of QFD is able to be utilized as concept development since it will be defining the critical parts and assembly. The critical product characteristic will be broken down and then translated into several key parts or assembly characteristics or specifications.

1. Determining Technical Requirements

According to part 1 House of Quality for Bamboo Cendani Perforation Machine, there are several technical requirements related specifically to machine assembly and parts and required furtherly analysis such as:

- CNC laser technology utilization
- Having an integration-friendly feature
- Capable material
- Good machine strength
- Have human safety features
- Built with ergonomic feature
- Make space-saving design
- Low maintenance cost
- Low usage cost

2. Determining Critical Part Requirements

From the process of analysis and cascading down the technical requirements related specifically to machine assembly and parts, a critical part is developed. The critical part characteristic is a few parts that are critical and able to define how well the technical requirement is achieved. Therefore table 4.2.30 shows critical part requirements from the technical part.

Table 4.2.29 Critical Part Requirement

Technical Requirements	Critical Part Requirement
CNC laser technology utilization	Use of CO2 laser cutter
Having integration-friendly feature	Detachable V-shape Gantry Body
Capable material	Aluminum material
Good machine strength	Fit-to-frame Metal Frame Joint, T-slot Fastener
Have human safety features	Black glass, openable hood, machine cover
Built with ergonomic feature	Linear actuator
Make space-saving design	Measured frame size
Low maintenance cost	Using a typical part model
Low usage cost	Integrated electrical system

3. Part Deployment Matrix

   After the determination of critical part requirements, the last step is by deploying the part deployment matrix by determining the correlation between technical requirements and critical part requirements. The following table is the result of the correlation on the part deployment matrix of the Bamboo Cendani Perforation Machine:

Table 4.2.30 Part Deployment Matrix

Row Number	Max Relationship Value in Row	Relative Weight	Critical Part Requirement / Demanded Quality	Use of CO2 Laser Cutter	Detachable Body	Aluminum Material	Fit-to-frame Metal Frame Joint, T-slot Fastener	Black Glass, Openable Hood, Machine Cover	Linear Actuator	Measured frame size	Using a typical part model	Integrated electrical system
1	9	11.78	CNC Laser Technology Utilization	9	3			9				9
2	9	9.68	Having Integration-Friendly Feature		9		1					
3	9	7.84	Capable Material			9						
4	9	9.10	Good Machine Strength		3		9		1			
5	9	10.56	Have Human Safety Features			1		9	3			
7	9	12.38	Built with Ergonomic Feature					3	9			
8	9	5.88	Make Space Saving Design							9	1	
9	9	6.30	Low Maintenance Cost	3	3	3					9	
10	9	7.28	Low Usage Cost	9								9
			Target or Limit Value	CNC Build CO2 Laser	Detachable V-shape Gantry Body	Alumunium Alloy Materiall 3003	L-shape Frane Joint, Fitted T-shape fastener	90% Black Glass, Openable Hood, Steel Machine Cover	300 mm Linear Actuator	75-100 cm height, 150 cm length	Use of 35 typical component	Integrate electricity with RDC6445G
			Minimize (▼), Maximize (▲), or Target (x)	x	▲	x	▲	x	x	x	▲	x
			Relative Weight	15.56	13.46	9.20	6.52	19.47	12.34	4.32	5.11	14.02

4.3 Concept Deployment

The following step after the development of the House of Quality and Part Deployment Matrix is the development of concept deployment. Concept deployment is the deployment of the design concept after the machine specification is obtained.

4.3.1 Laser Configuration

The laser configuration for the perforation machine needs to be conceived in order to obtain a specific configuration that can be applied to perform the intended performance. Therefore, the research is conducted in coordination with the Manufacturing System Laboratory to research the desired laser configuration needed for the perforation machine. As a result, here are the configuration obtained from the discussion:

Table 4.3.1 Laser Configuration

No	Type	Result
1	Laser Type	Minimum 80 Watt CNC CO2 Laser
2	Feeding Speed	100mm/s
3	Nozzle Distance	1 cm

4.3.2 Feasibility Study Analysis

A feasibility study is conducted in order to evaluate the feasibility of the developed machine with the current existing production process using manpower as well as the drill machine.

The objective of this feasibility study analysis is to compare the costs, benefits, and risks associated with using a laser cut machine, drill machine, or manpower to produce perforated fishpole bamboo with 3 holes per day. The study will use a comparative approach to analyze the three options in terms of their capital and operational costs, labor requirements, production efficiency, and quality of output.

The following assumptions will be used in the analysis:

a) The cost of electricity in Indonesia is IDR 1,500 per kWh.
b) The bamboo used is of good quality and consistent thickness.
c) The output is consistent in terms of size, shape, and quality.
d) The margin obtained from the sale of the product is 20%.

e) The cost of labor is IDR 80,000 per day per worker.

f) The study period is one month (30 days)

1. Laser Cutter

Assuming the use of a high-end laser cut machine with a power of 80 watts, and a cutting speed of 100 mm/s, it may take around 10 to 20 seconds to perforate a single bamboo sheet 65 with 3 holes. Using the formula, the estimated output of perforated bamboo sheets with 3 holes per day is as:

$$6\ hours\ x\ 60\frac{minutes}{hour} x\ 60\frac{seconds}{minute} \div\ 15\frac{seconds}{bamboosheet}$$
$$=\ 1{,}440\ bamboo\ sheets\ with\ 3\ holes$$

However, with the average number of bamboo per sheet is around 125 bamboo. The number of products able to produce is $\frac{1{,}440}{25} \approx 12\ products\ per\ day$. The average price of the product is around IDR 500,000 and assuming the company takes a 20% margin on it.

The cost of purchasing a high-end laser cut machine with 80 watts of power is around IDR 40-90 million. The operational cost for running the machine for 6 hours per day is around IDR 49,500 per day, assuming a power consumption rate of 5.5 kW per hour and an electricity cost of IDR 1,500 per kWh. Assuming one operator is required to operate the laser cut machine, the labor cost for one day is IDR 80,000. So the total expense in a month is:

- Margin: IDR 100,000/product
- Output/month: 360 products
- Capital Cost: IDR 65 million
- Operational Cost: IDR 1,485,000 per month (IDR 49,500 x 30)
- Labor Cost: IDR 2,400,000 per month (IDR 80,000 x 30)

2. Drill Machine

Assuming the use of a high-speed drill machine with a power rating of 800 watts, it may take around 30 to 60 seconds to drill a single bamboo sheet with 3 holes. The estimated output of perforated bamboo sheets with 3 holes per day is as:

$$7\ hours\ x\ 60\ minutes/hour\ x\ 60\ seconds/minute\ \div\ 45\ seconds/bamboo\ sheet$$
$$=\ 560\ bamboo\ sheets\ with\ 3\ holes$$

However, the average number of bamboo per sheet is around 125 bamboo. The number of products able to produce is $\frac{560}{125} \approx 5\ products\ per\ day$.

The cost of purchasing a high-speed drill machine is around IDR 4 million. The operational cost for running the machine for 7 hours per day is around IDR 21,000 per day, assuming a power consumption rate of 2 kW per hour (2000 watts x 7 hours ÷ 1,000) and an electricity cost of IDR 1,500 per kWh. Assuming one worker is required to operate the drill machine, the labor cost for one day is IDR 80,000. So, the total expense in a month is:

- Margin: IDR 100,000/product
- Output/month: 150 products
- Capital Cost: IDR 4 million
- Operational Cost: IDR 630,000 per month (IDR 21,000 x 30)
- Labor Cost: IDR 2,400,000 per month (IDR 80,000 x 30)

3. Manpower

Assuming the use of manpower to manually perforate the bamboo sheets with a drill, it may take around 2 to 3 minutes to drill a single bamboo sheet with 3 holes. The estimated output of perforated bamboo sheets with 3 holes per day:

$$7\ hours\ x\ 60\ minutes/hour\ \div\ 2.5\ minutes/bamboo\ sheet$$
$$=\ 168\ bamboo\ sheets\ with\ 3\ holes$$

However, the average number of bamboo per sheet is around 125 bamboo. The number of products able to produce is $\frac{168}{125} \approx 1\ product\ per\ day$. Total cost for one month:

- Labor Cost: IDR 2,400,000 per month (IDR 80,000 x 30)

The summary table for the feasibility analysis is as follows:

Table 4.3.2 Feasibility Comparison

	Laser Cutter	**Drill Machine**	**Manpower Only**
Capital Cost	IDR 65,000,000	IDR 4,000,000	No capital cost
Operational Cost	IDR 1,485,000	IDR 63,000	No operational cost
Labor Cost	IDR 2,400,000	IDR 2,400,000	IDR 2,400,000
Output per day	12 products	5 products	1 product
Output per month	360 products	150 products	30 products

Then, the earn and spend simulation for all alternatives are as follows:

Table 4.3.3 Earn and Spend Simulation

	Laser			Drill			Manpower		
Mon	Spent	Earn	Subtotal	Spent	Earn	Subtotal	Spent	Earn	Subtotal
1	68,885,000.00	36,000,000.00	(32,885,000.00)	7,030,000.00	12,000,000.00	4,970,000.00	2,400,000.00	3,000,000.00	600,000.00
2	3,885,000.00	36,000,000.00	(770,000.00)	3,030,000.00	12,000,000.00	13,940,000.00	2,400,000.00	3,000,000.00	1,200,000.00
3	3,885,000.00	36,000,000.00	31,345,000.00	3,030,000.00	12,000,000.00	22,910,000.00	2,400,000.00	3,000,000.00	1,800,000.00
4	3,885,000.00	36,000,000.00	63,460,000.00	3,030,000.00	12,000,000.00	31,880,000.00	2,400,000.00	3,000,000.00	2,400,000.00
5	3,885,000.00	36,000,000.00	95,575,000.00	3,030,000.00	12,000,000.00	40,850,000.00	2,400,000.00	3,000,000.00	3,000,000.00
6	3,885,000.00	36,000,000.00	127,690,000.00	3,030,000.00	12,000,000.00	49,820,000.00	2,400,000.00	3,000,000.00	3,600,000.00

4.4 Proposed Design

After the development of the House of Quality (HOQ) and Part Deployment Matrix obtained from data collection such as interviews, FGD, and closed questionnaires, the further step is by developing the proposed design. The proposed design for Bamboo Cendani Perforation Machine will furtherly be discussed with the owner of PT. Dekorasia Jayakarya in order to able to provide the design which suitable to the company's requirements.

4.4.1 Product Design

The following is the proposed design for Bamboo Cendani Perforation Machine that is designed using 3D design software. The design will be furtherly forwarded and discussed with stakeholders.

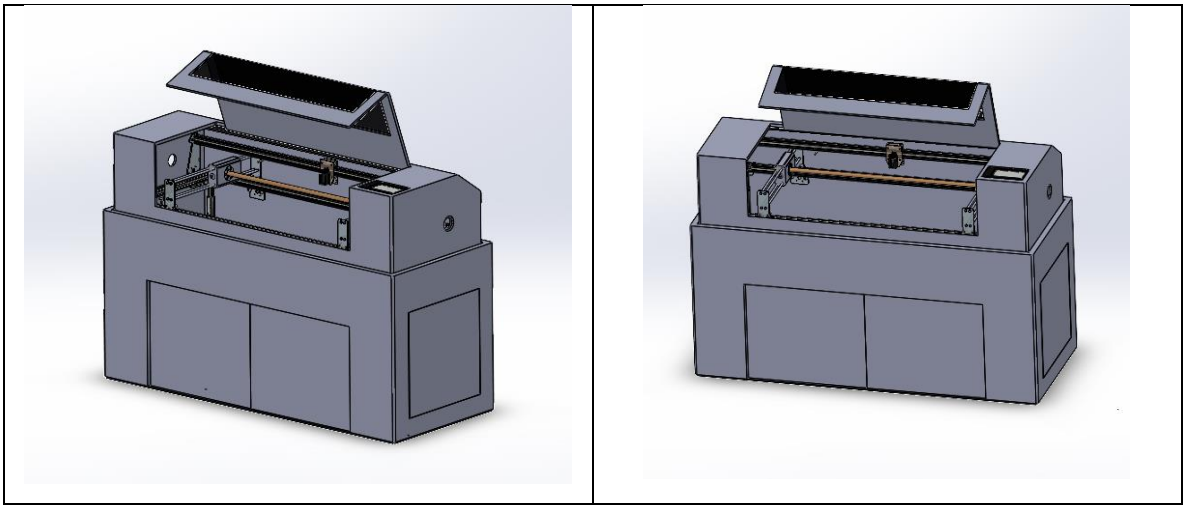


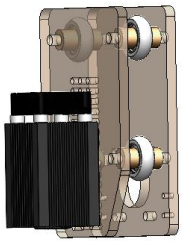
Figure 4.4.1 Product Design

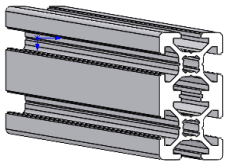
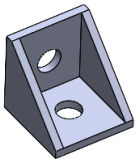
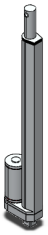
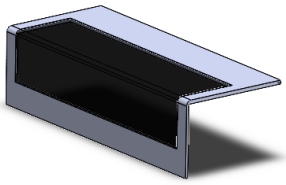
4.4.2 Feature Design

The proposed design is not only for the whole design but also the product feature design that structured the designed machine in 3D design. Thus, the designed features will be furtherly discussed as well in order to obtain the specified and ideal design for Bamboo Cendani Perforation Machine.

The following Table 4.3.1 is the figure of the designed feature for the Bamboo Cendani Perforation Machine which covers:

Table 4.4.1 Machine Features

Feature	Figure
Laser	

Feature	Figure
Alumunium Gantry Frame	
T-nut Fastener	
Frame Joint	
Height Adjustor	
Cover Hood	

Feature	Figure
Controller	

The attributes that are adopted in machine development are based on the data analysis with QFD. According to the voice of the customer, the company needs a machine that can afford high performance. Thus, the machine is provided with a laser cutter with the aim of faster the working process. The height adjustor is included because of the requirement for conformance when working with the specified machine. The cover hood is required to guard the operator for the machine operating process as well as protect the eyes from the laser beam produced. Also, a chuck is placed in order to support and enhance the operation process, since the workpiece is specified which is bamboo with specific shape characteristics.

4.5 Design Evaluation

The process of evaluation is executed involving the manager and owner of PT. Dekorasia Jayakarya. The evaluation process is performed through FDG 3 which is aimed to evaluate the proposed design of the Bamboo Cendani Perforation Machine.

Accordingly, there is input and suggestions regarding the proposed design of the Bamboo Cendani Perforation Machine which is obtained by performing FGD 3.

Table 4.5.1 Design Evaluation

No	Evaluation	Suggestion
1	1 laser for the whole workpiece is taking time	Add a laser for every hole perforated.

	and still needs a performance improvement.	
2	The machine is proposedly able to be integrated with another process	The addition of wire feeding operation in a machine.

4.6 Machine Re-design

In response to the suggestion from FDG 3, the machine redesign is performed which is by adding and evaluating the required attributes.

4.6.1 Product Re-design

The following is the redesigned Bamboo Cendani Perforation Machine in response to the stakeholders' requirements.

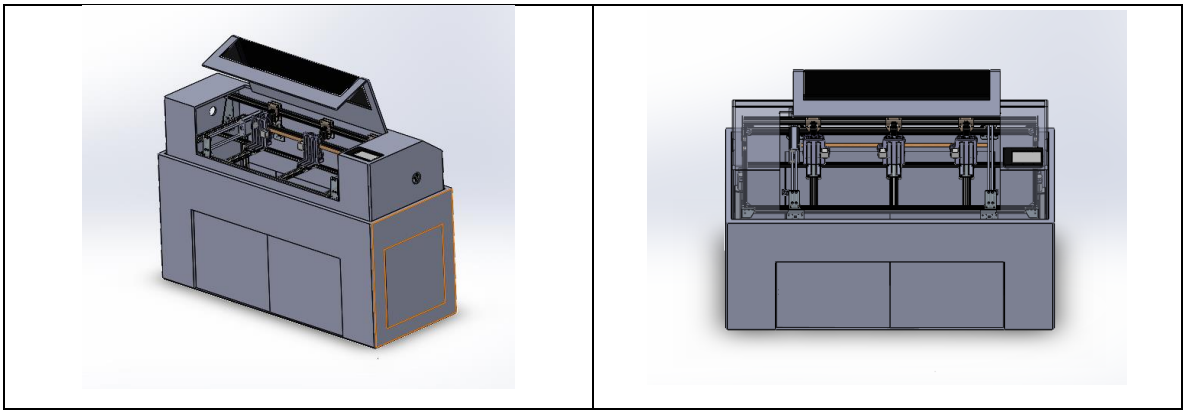
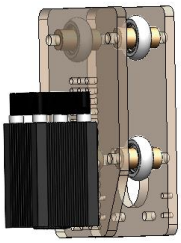
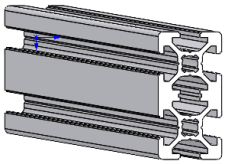
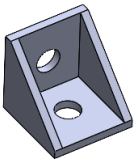


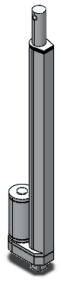
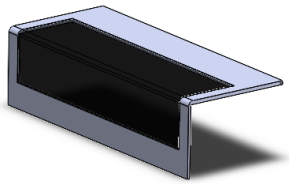
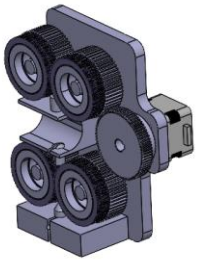
Figure 4.6.1 Product Redesign

4.6.2 Feature Re-design

On the other side of product redesign, there should be considering the additional features included in the final product suggestion which also constructs the component machine to be whole. Moreover, the designed feature for the final design of the Bamboo Cendani Perforation Machine is including the:

Table 4.6.1 Redesigned Features

Feature	Figure
Laser	
Alumunium Gantry Frame	
T-nut Fastener	
Frame Joint	

Feature	Figure
Height Adjustor	
Cover Hood	
Controller	
Wire Feeder	

The additional feature added is the wire feeder component. The wire feeder component is aimed to be able to perform the integration process of perforating and wire feeding. The wire feeder is aimed to be placed according to the position of the perforation process to get process

precision in response to performance improvement. The additional feature added is the giving of a three laser and wire feeder in accordance with the hole location.

CHAPTER V

RESULT AND DISCUSSION

4.1 Customer Requirement Analysis

This study aims to design a Bamboo Cendani Perforation Machine. This machine was designed with the aim of being able to improve the progress and performance of the production process in producing products from the cendani screen bamboo production line. In its implementation, the research respondents included 12 respondents including owners, managers, and subcontracted workers.

In FGD 1 which was carried out to find the first problem, several needs were found that could be developed to help with existing problems in the company, especially in the production process. In FGD 1, input was obtained on several problems and development ideas from the problems obtained.

Some of the main problems faced by the company include the high use of human labor in the production process, especially the process of perforation holes in cendani bamboo products. Then there is still a high number of defective goods resulting from the production process, causing a reduction in the production capacity of goods according to standards. There is diversification of results and inconsistency in quality as well as inefficient use of time and human resources as well as many complaints of illness which interfere with the productivity of workers in the production process. Based on this problem, several ideas were discussed, which the design of a machine that can automate the production process, features on the machine that can increase precision in the form of laser cutting, and adjustable machine height to prevent back pain. The results obtained in FGD 1 were then used as the basis for designing a perforation machine.

After the FGD 1 was carried out, interviews were then conducted with 10 respondents to obtain the Voice of Customer which would then be used in developing the perforation machine design. From the results of the interviews, the attributes that describe the customer requirements that need to be considered include progressive, durable, safe, easy to use, compact, and low cost.

The customer's need for progressive attributes can be interpreted that they need for a machine that can increase productivity and production capacity. Increased productivity can be interpreted that the production process on the cendani bamboo line having increased. Improvements in the production process can be obtained if problems related to productivity can be found in the production process. One of the main problems is that manpower is still widely used in the production process which causes an erratic amount of production capacity as a result of inconsistencies produced by human power. Therefore we need a tool that can automate the monotonous production process so that productivity can be increased. As a result of increased productivity, an increase in production capacity will also be obtained.

The customer's need for the durable attribute means that the product to be developed needs to consider the quality of its constituents so that it can have durability and long service life. In fulfilling this attribute, it is necessary to choose good frame materials and features so that they can have good durability as well. The frame material chosen is aluminum which besides being lightweight also has good resistance as a whole machine frame.

Then safe is another requirement needed in making the Bamboo Cendani Perforation Machine. The need for the safe attribute can be interpreted as the need for security features in the machine development process. The necessary safety features are in the form of protection against the machining process itself which produces high heat. In addition, it also requires eye protection against laser light in the form of dark glass that can reduce the impact of bright light from the laser. In addition, a user manual is also needed regarding dangerous areas on the machine that can be at risk of causing an accident.

Then the need for ease of use required by the customer can be interpreted that the need for convenience in operating the machine being developed. The convenience required can be in the form of ease of use and ease of repair. Ease of use can be assisted by making a

user manual and also training workers in operating the machine. For ease of repair, it can be improved by making machine manual books and parts for mechanics. So that the process of use and repair can be simplified.

The compact attribute obtained from customer requirements can be interpreted that a compact tool that is needed and can be placed in various places. This is based on the needs of companies that have limited space in their production sites plus there are several production lines for each product they produce, so a compact attribute is needed in the development process. The compact attribute can be obtained by considering space efficiency in making the machine frame and also the space for tool movement in the production process so that a compact machine is obtained.

The last attribute obtained from customer requirements is low cost, which means that the product being developed must have cost considerations in its manufacture. Cost includes the cost of maintenance and usage costs in the production process. The cost consideration can be made by considering the number of components used and also the complexity of the machine. In addition, the use of several similar materials can also reduce maintenance and repair costs if needed.

4.2 Design Specification Analysis

Determination of specifications in the Bamboo Cendani Perforation Machine research was carried out using the Quality Function Deployment (QFD) method. The QFD method is carried out through several stages such as taking the Voice of Customers (VOC) in which the main constituent attributes of customer needs will be obtained. The next stage is determining the Important Rating (IR) which is carried out through interviews. Important rating is useful for assessing the level of importance of an attribute to be further developed into technical requirements. Important Rating (IR) numbers were obtained for the customer requirement attribute including progressive with an IR value of 4.2, then durable with a value of 3.4, safe attribute with a value of 3.8, ease of use with a value of 3.7, then compact with a value of 2.8 then low cost with a value of 3.0.

After the Important Rating (IR) is obtained, the next step is to determine the technical requirements which are translated from customer requirements so that a technical

requirement can be obtained which will become a measurable design feature. Progressive attributes obtained from customer requirements when converted into technical language can be interpreted by utilizing automation using laser technology and also making features that are easy to integrate. Then the durable attribute can be translated as a capable material selection and also a reinforcement of the machine frame structure. When the safe attribute is converted into technical requirements, it can be interpreted by making SOPs and also providing safety features for the product being developed. The ease of use feature can be translated into technical requirements as providing ergonomic features with adjustable height and also creating a user manual for machine use. Furthermore, compact requirements can be converted into technical requirements as the manufacture of machines that do not take up much space. Then for low-cost requirements, it can be translated that it is necessary to emphasize usage costs which can be emphasized on electricity costs and also maintenance to be able to reduce machine production costs.

The next step after translating the attributes of the customer requirements into technical requirements, the next step is determining the targets of the predetermined technical requirements. As in laser technology utilization which targets the use of CNC laser technology with CO2 power. In addition to the technical requirements for integration-friendly features, it is targeted to use a V slot gantry frame which is also given space for integration of 40cm in width and 140 lengths to make it easier for integration-friendly features to be integrated with related production processes. Then for the technical requirement capable material, the material targeted for use in the manufacture of frames on the machines being developed is aluminum due to the sturdiness and also the weight of the material which is light enough to make it easier to manufacture machines. Furthermore, the technical requirements for machine strength can be targeted by providing a suitable frame joint for the V slot gantry frame which is also supported by a Tslot fastener to strengthen and tighten the machine frame. Furthermore, for the technical requirements for human safety features, it can be targeted by providing a cover hood equipped with protective glass, besides that a safety design is also needed, especially to protect operators from the work processes of machines that use laser technology. For SOP technical requirements, it is targeted to make machine completeness such as SOP for machine use and operation so that it can be used

properly and correctly. Then for the technical requirement ergonomic feature, a feature is added to adjust the height of the machine with sitting and standing postures which can be adjusted according to the needs of the operator, with a height range between 75 cm to 100 cm. Then for technical requirements space saving is targeted with a compact size, which length = 150cm, width = 80cm, and height = 75 – 100 cm which fits the needs of the components and also the size of the cendani bamboo workpiece. For technical requirements, manual instructions can be targeted with the manufacture and supply of machines in the instruction manual in the form of a combination of components and how to operate and repair. Then low maintenance costs can be targeted by reducing the different component parts so that the repair and maintenance process can be reduced in cost. Then for the low usage cost technical requirement, this can be done by selecting the most suitable electrical component needed and also reducing the amount of need for electrical components.

Then after the target is determined, the next step is to determine the relationship between customers and technical requirements which are assessed in 3 score categories. Attributes that have a strong relationship will be given a value of 9, a medium correlation of 3 scores, and a low correlation will be given a score of 1. On the basis of these calculations, progressive customer requirements are given a score of 9 for direct correlation with the use of laser cut technology which simultaneously automates the punching process in the cendani bamboo production process. Apart from that, the provision of convenience for integration also has a strong correlation with progressive attributes, where good integration will also have a direct effect on productivity and progressivity. Then progress can have a weak relationship to low usage cost because if integration is added, it means that the number of components in the automation process will also increase. So the cost of using the machine will increase. However, this can be tricked by selecting tools that are low in watts and also efficient in power, especially components with electricity.

Furthermore, the durable attribute has a strong correlation with material capability. This is because the selection of materials in the machine development process can directly affect the durability of the machine itself so durability has a strong relationship with the selection of capable materials including materials in laser machines and other supporting components such as chucks and drive components. Besides that, the strength, especially the

strength of the frame, greatly influences the durability of the machine. That's because the manufacture and preparation of a strong frame can affect the durability of the machine. Apart from that, it is also necessary to pay attention to the strength of the joints between the frames because it is closely related to the strength of the machine in carrying out the production process.

The safe attribute has a strong correlation with the technical requirements of the human safety factor. The provision of the human safety factor greatly influences safety attributes, especially operator safety because even though the machine has used automation, the provision of safety attributes can greatly help provide safety to operators who operate the machine. The safe attribute also has a strong correlation with the machine's SOP. which contains related safety and machine operational procedures. Then the safe attribute also has a correlation with the ergonomic feature where the ergonomic feature can improve health and safety factors, especially for operators who operate the machine but does not directly affect the machine safety factor, so it only has a medium correlation. Finally, the safe attribute has a strong correlation with the manual instruction of the machine because the instruction manual can increase awareness of the important parts of the machine as well as provide safety and usage instructions related to the components and features of the machine.

Furthermore, the ease of use feature has a weak correlation with the attributes of laser technology utilization. The application of laser technology which is a relatively new technology in the manufacturing industry will have an impact on the ease of use, but not too significant because laser technology applies an automation system that can reduce the operator's role in the production process. Then the application of the integration-friendly feature will also have a weak correlation. The addition of integration features will increase the complexity of machine operations and processes, but this will only have an effect if this integration-friendly feature is used, which was not used in the initial design. So that this feature by itself does not add complexity which will affect the ease of use attribute. And also the added features need to be reviewed for complexity and their use whether they require a manual operation or not so that this correlation is given a weak correlation score. Next is the correlation with the technical attribute safety factors which have a strong correlation. The strong correlation is based on the effect of safety features on the ease of operation of the

machine where if the machine has a low-security system it will make the machine difficult to use and operate by the operator. Furthermore, the correlation between ease of use and the preparation of SOPs for machine use has strong correlation. The strong correlation is based on the strong correlation between the making of SOP which will explain the safety factor and also the use of the machine which will affect the ease of use factor. Then the correlation with the technical requirements of ergonomic features has a strong correlation. The strong correlation is based on ergonomic features that adjust to the human body which will provide convenience and comfort in operating and using the machine. The last one is a correlation with the technical requirements for making an operation manual which will affect how to use and operate and also related to important matters in machine components and parts, so it has a strong correlation. Where the clarity of machine components as well as machine-related warnings and instructions will support the ease of use of the machine itself.

Then for the compact customer requirement attribute, it has several correlations related to technical requirements. The first is the weak correlation with mechanical strength. The compactness of a machine will have an influence on its strength if not thought about properly. Components that are more concise and sizes that are tailored to the needs will affect the strength of the frame. However, if it is supported by good joints and supports, the strength of the machine can be increased. So compactness and machine strength have a weak correlation. Then the correlation between the compact attribute and the technical requirement ergonomic feature has a score for medium correlation. When calculating and considering ergonomic features, this size will be used instead of reducing the size as compact as possible. The implementation is the use of ergonomic features in the form of average sitting and standing heights which are applied to become the height limit of the machine itself. However, ergonomic features do not always directly affect size, where the application is that only sitting and standing height can be applied to perforation machines due to the need to consider the configuration of the machine and also the components inside, so it is only given a score for a medium correlation. Finally, the compact attribute has a strong correlation with space-saving design. Taking into account the workpiece size, machine configuration, and components, compactness can be achieved.

Attributes of customer requirements for low cost have a correlation with the technical requirements of laser technology utilization where the use of laser technology will have a significant impact on the costs of using and manufacturing perforation machines. However, the cost can be adjusted according to needs and has relativity related to the selection of a laser brand so that it has a medium correlation. Then the material selection also has an influence on the overall machine manufacturing costs. So it has an intermediate correlation. Then low cost has a strong correlation with low maintenance cost technical requirements and low usage costs which are direct correlations with low-cost customer requirement attributes.

Then after determining the correlation between technical requirements and customer requirements, the required weight is calculated where the required weight is obtained from the important rating multiplied by the relative weight for each attribute. Then the result is obtained where the required weight that has the greatest value is the machine SOP development and also the instruction manual provided which has the same value of 323, which means that the technical requirement has a high level of importance. In contrast, space-saving design is a technical requirement that has the lowest requirement weight so the technical requirement has the lowest level of importance with a score of 120.6.

The next step in the development of a perforation machine is to determine the correlation matrix between technical requirements. Laser technology utilization has a positive correlation with integration-friendly features and also has a negative correlation with low maintenance costs and low usage costs. Then integration friendly feature has a positive correlation with laser technology utilization and also has a positive correlation with capable material and also machine strength but has a negative correlation with space-saving design and low maintenance cost. Then capable material features have a positive correlation with integration-friendly features, machine strength, and human safety features. Technical requirement machine strength has a positive correlation with capable material, integration-friendly features, and also with human safety features. Human safety factor has a positive correlation with machine strength, capable material, SOP, ergonomic features, and instruction manuals. Then the making of SOP has a positive correlation with the human safety factor and also the instruction manual. Then the technical requirement ergonomic features have a positive correlation with the human safety factor. Manual instruction has a positive

correlation with SOP and human safety features. Furthermore, space-saving design has a negative correlation with integration-friendly features. Low maintenance cost has a positive correlation with low usage cost but has a negative correlation with laser technology utilization and integration-friendly features. Lastly is low usage cost which has a negative correlation with laser technology utilization and has a positive relationship with low maintenance costs.

Then after the correlation matrix is determined, the direction of improvement is also determined by identifying the technical requirements that need to be maximized or minimized. Laser technology utilization has an improvement direction for targets because laser capacity and specifications will be determined and adjusted according to needs. Then for the technical requirement integration-friendly feature, a direction of improvement is given to be maximized so that it can accommodate several integration features. Then the capable material is given direction improvement targets because the targeted material can not only have strength but suitability when it will be applied to become a machine frame. Then the technical requirements for machine strength are given direction to be maximized because it is necessary to maximize engine power. Just like machine strength, the human safety feature is given direction improvement to be maximized so that operator safety and comfort in operating the machine. Then for SOP features, directions for improvement are given, the same as ergonomic features, manual instructions, and space-saving designs that cannot be maximized or minimized. Meanwhile, low maintenance costs and low usage costs are targeted to be maximized to reduce maintenance costs and usage.

The next step is to determine and evaluate customer competitive evaluation (CCE) which is distributed through a closed questionnaire. From the customer competitive index (CCE) the attributes of the customer requirements of the product developed with similar existing products will be evaluated. Of the six attributes evaluated, the ease of use attribute cannot be compared according to discussion with the experts due to the nothingness of the significant parameter of comparison. The ease of use itself, accordingly, must be evaluated based on the real experience of the user in order to compare it with the current machine. Accordingly, the results obtained were three attributes of the machine being developed,

which were progressive, durable, and safe, which had a higher score than existing products. While compactness and low cost get lower results than existing products.

Then in setting goals, which table 4.2.21 has shown the calculation of the goal value of each attribute of the customer requirements. The progressive and durable attributes have the same goal value of 3.1. Then the safe attribute gets a goal value of 2.95. Then the compact attribute has a goal value of 2.65 while low cost has a goal score of 3.15.

The next stage is determining the sales point as the selling point of the product to be developed. The results obtained from the calculation of the sales point are the progressive, durable, and safe attributes getting a value of 1.5 which these attributes will greatly provide added value and sales points if these attributes can be developed and realized.

After determining the sales point, then the improvement ratio is calculated, which shows the amount of improvement that needs to be done for the product being developed. The results in Table 4.2.25 show that the progressive, durable, and safe attributes have a value below 1 which means that the specifications that have been designed do not require improvement. Then attributes such as compact and low cost still require improvement with a score above 1.

Furthermore, the column weights are also calculated and the results are as shown in Table 4.2.26 where the progressive, durable, and ease of use attributes have a weight of 4.65 so they have the highest development priority. Then the safe weight has a value of 4,425. Then the low-cost attribute has a row weight of 3.78 and compact has a score of 2.65 which means that the customer does not really need a compact machine.

After the column weights are determined, the next step is to determine the required action for the attributes of the product being developed. Based on the results in Table 4.2.28, the results show that the progressive, durable, safe customer requirements get action C, which means that these attributes only need to be maintained in quality. Meanwhile, the customer requirements for ease of use, compactness, and low price need to be evaluated because the performance of the machine is still below that of similar products.

After the development of the first HOQ which ended in determining the action, then house 2 was made in the form of part deployment, which is a table that identifies advanced technical factors for the development of perforation machines. In this table, the critical part requirements are determined which are the advanced technical requirements of house 1. The critical part requirements obtained are parts that have a high level of importance that need to be considered in the development of perforation machines so that customer requirements can be obtained. The critical part requirements obtained are the Use of a CO2 laser cutter, detachable v-shape gantry body, aluminum material, fit-to-frame metal frame joint, t-slot fastener, black glass, openable hood, machine cover, linear actuator, measured frame size, using typical part models, and integrated electrical systems.

Then it is the same as house 1 where it is calculated and the required weight is obtained from the matrix calculation. The calculation of the matrix in question is the determination of the correlation matrix between critical part requirements and demand quality which is similar to the calculation of the house of quality wherein the relative weight is obtained from the calculation of the important rating with the correlation relationship between the critical part requirements and the demanded quality. Then a score for the relative weight for the critical part requirement is generated, which is Black Glass, Openable Hood, and Machine Cover which has the largest relative weight, 19.47, where this critical part requirement needs to be given priority for development. Then the Use of a CO2 Laser Cutter has a score of 15.56, an Integrated Electrical System has a value of 14.02, a Detachable V-Shape Gantry Body has a value of 13.46, Aluminium Material obtains a value of 9.2, Fit-to-frame Metal Frame Joint, T-slot Fastener which receives a value of 6.52, Using a Typical Product Model which gets a score of 5.11 and the lowest is Measured frame size which gets a score of 4.32.

4.3 Feasibility Study

Based on the analysis, using a laser cut machine is the most efficient and fastest method to produce perforated fishpole bamboo sheets with 3 holes per day. Although it has a higher capital and operational cost, the output is significantly higher and the production process is more efficient, resulting in a lower labor cost per sheet.

On the other hand, using a drill machine with manpower is a feasible option for small-scale production, but it has a lower output and requires more labor, resulting in a higher labor cost per sheet.

Using manpower only is not a cost-effective option, as it requires a significant amount of labor and results in a low output, which leads to a high labor cost per sheet.

4.4 Product Design, Feature, and Evaluation

After conducting data analysis to obtain specifications for the development of the Bamboo Cendani Peforation Machine using House of Quality (HOQ) and also critical parts using the Part Deployment Matrix, then a design for the Bamboo Cendani Peforation Machine was made with 3D design software so that a visual design can be produced from quality, components, and parts that have been determined. Then a 3D design is produced with predetermined features. The first feature is the use of a laser for punching holes in bamboo which is supported by a CNC system for movement on the X, Y, and Z axes. Then the provision of a height adjuster with a linear actuator to be able to increase and decrease the height of the machine in order to support the ergonomic features of the machine. Then added the engine body and hood cover with sight reduction as an engine safety feature in accordance with quality requirements. Then use the chuck as a specific differentiator with a universal CNC laser machine made specifically for objects that have cylindrical dimensions such as bamboo.

After the proposed design for the Bamboo Cendani Perforation Machine has been made, it will then be evaluated for suitability with customer needs. From the evaluation process, the results show that there are several inputs related to the design features that have been planned. The first is input over time which tends to be long when using one laser to punch 3 holes for two sides on two opposite surfaces. So that there is input to provide a laser on each part to be perforated, namely as many as 3 holes for the Bamboo Cendani Screen product. This proposal might increase the performance of the machine but on the one hand, it will obviously greatly increase the cost of manufacture, maintenance costs, and the cost of using the machine itself. Then the second evaluation is the need for the implementation of

integration-friendly features to be realized. So that a suggestion emerged to integrate the process of punching holes with feeding and wire-feeding of bamboo to shorten the production process. So it is necessary to make a system for wire feeding on the machine by integrating the perforation process so that movable parts are designed for the chuck, laser frame, and also for wire feeder.

CHAPTER VI

CONCLUSION AND SUGGESTION

6.1 Conclusion

The summary obtained according to this research is the design of a perforation machine for fishpole bamboo in PT. Dekorasia Jayakarya which is in accordance with the requirements of the stakeholders. The design result that has been processed with Quality Function Deployment is that the design of the perforation machine has specific requirements such as the CNC application of laser cutting machine to perform the perforation process, usage of V-slot gantry frame for the movable and attachable feature, T-slot fastener and L shaped frame joint for the machine strength, a linear actuator for adjustable height for ergonomic feature, cover hood and machine cover for the safety features, and integrated electrical control feature. The additional feature added after the design evaluation is by adding the wire feeder for the additional feature to the machine.

6.2 Suggestion

The result obtained by the research furtherly must pay some attention to the following factors:

1. The design for the perforation machine for fishpole bamboo can furtherly be continued for the manufacturing or implementation result.
2. Further research must be paying more attention to the electricity efficiency and feature efficiency of the machine, as well as the development cost of the machine itself.

REFERENCES

Antu, E. S., & Djamalu, Y. (2018). DESAIN MESIN PENCACAH SAMPAH ORGANIK RUMAH TANGGA UNTUK PEMBUATAN PUPUK KOMPOS. *Jurnal Teknologi Pertanian Gorontalo*, 57-65.

Arhamsyah. (2016). THE MANUFACTURING AND UTILIZATION OF THE BAMBOO. *Jurnal Riset Industri Hasil Hutan*, 30 – 35.

Arsad, E. (2016). The Technology Process and Used of Bamboo. *Jurnal Riset Industri Hasil Hutan*, 45 –52.

Bambang. (2022, February). Bamboo Panels Indonesia. (Sabila, Interviewer) Retrieved from Dekor Asia Indonesia.

Bess, Moore, N., & Wein, B. (1987). *Bamboo in Japan.* Tokyo: Kodansha International.

Bora, Ansyar, M., Sanusi, & Isdar, A. (2018). Desain Produk Jasa Layanan Dengan Menggunakan Metode Quality Function Deployment (QFD) Di Rusun Fanindo. *Jurnal Industri Kreatif*, 37-50.

Brandt, E., & Messeter, J. (2018). *Facilitating participatory design: Principles and practices.* Routledge.

Caristan, C. L. (2004). *Laser Cutting Guide for Manufacturing.* Houston: Society of Manufacturing Engineers.

Chrisdio, & Benedikta. (2020). Perancangan Meja dan Kursi Komputer Sesuai Dengan Sistem Smart Class pada Laboratorium Desain Produk dan Inovasi Institut Teknologi Del. *Jurnal Teknik Industri*, 255-265.

Cohen, L. (1995). *Quality function deployment: how to make qfd work for you. Addison-Wesley.* Reading Mass: Addison-Wesley.

Elly, L., & Miftahul, I. (2020). Perancangan Produk AquascapeDengan Metode Quality Function Deployment(QFD). *Jurnal Terapan Teknik Industri*, 21-29.

Erlangga, D. A. (2018). *PERANCANGAN MESIN PENIRIS MINYAK (SPINNER) UNTUK KEBUTUHAN DAPUR RUMAH TANGGA DENGAN MENGGUNAKAN METODE TRIZ.* Sleman: DSpace UII.

Faizal, A., Luthfianto, S., & Nurwildani, F. (2017). DESAIN PENGEMBANGAN PRODUK WALLSHELF MENGGUNAKAN INTEGRASI QFD DAN DFMA DI UD. XYZ. *Jurnal Bidang Teknik*, 11-16.

G.E. Mathis Company. (2019). *Laser Types & Configurations for Cutting Sheet and Plate Metal*. Retrieved May 2022, from G.E. Mathis Company: https://www.gemathis.com/laser-types-configurations/

Gaoa, X., Zhua, D., Fanc, S., Md Zillur, R., Shuaicheng, G., & Feng. (2022). Structural and mechanical properties of bamboo fiber bundle reinforced composite (A review). *Journal of Materials Research and Technology*, 1-36.

Gibson, J. P. (2021). Data-Driven Product Design: Strategies for User-Centered Design. *IEEE Transactions on Professional Communication*, 30-44.

Ginting, R., Batubara, T. Y., & Widodo. (2017). DESAINULANGPRODUK TEMPAT TISSUEMULTIFUNGSI DENGAN MENGGUNAKAN METODE QUALITY FUNCTION DEPLOYMENT. *Jurnal Sistem Teknik Industri,*, 1-9.

Hara, T. (2018). Integrating Usage Information into Quality Function Deployment for Further PSS Development. *Industrial Product Service System*, 21-25.

Hardian, & Sari, D. K. (2018). PERANCANGAN DESAIN KEMASAN PRODUK MINUMAN TEH DENGAN METODE QUALITY FUNCTION DEPLOYMENT (QFD). *Jurnal Teknik Industri*, 36-47.

Kanagaraj, K. T. (2018). An Integrated Approach for Quality Improvement using Quality Function Deployment and Lean Six Sigma. *International Journal of Engineering and Advanced Technology*.

Kelchner, S. A. (2013). Higher level phylogenetic relationships within the bamboos (Poaceae: Bambusoideae) based on five plastid markers. *Molecular Phylogenetics and Evolution*, 404 - 413.

Li, R., Guo, X., & Cao, P. (2018). OPTIMIZATION OF LASER CUTTING PARAMETERS FOR RECOMBINANT BAMBOO BASED ON RESPONSE SURFACE METHODOLOGY. *WOOD RESEARCH*, 275-286.

Loomis, W. a. (1967). *Botany.* New York: Holt, Rinehart and Winston.

Maimunah, H., Lisha, D., & Atsari, I. (2019). Redesign of Brownies Biscuit Packaging using Quality Function Deployment (QFD) Method. *TEKNOTAN*, 39-46.

Ministry of Forestry. (2014). Bambu dan Kegunaannya . Indonesia.

Mohamad, S., & Masruki, K. (2021). DESAIN DAN SIMULASI TEGANGAN PADA MESIN CNC LASER CUTTING UNTUK PRODUK BERBAHAN ACRILIC. *Jurnal CRANKSHAFT*, 39-48.

Nurmianto, E., Wessiani, N. A., & Megawati, R. (2018). DESAIN ALAT PENGASAPAN IKAN MENGGUNAKAN PENDEKATAN ERGONOMI, QFD DAN

PENGUJIAN ORGANOLEPTIK. *Jurnal Manajemen dan Teknik Industri Produksi*, 68-82.

Parthiban, A., Sathish, T., Chandran, S. S., Venkatesh, R., & Vijaya, V. (2019). OPTIMIZATION OF CO2 LASER CUTTING PARAMETERS ON AUSTENITE STAINLESS STEEL USING GREY RELATIONAL ANALYSIS. *International Journal of Mechanical Engineering and Technology (IJMET)*, 984-992.

Paulina, D., & Ketut Purnawati, N. (2018). DESAIN KUALITAS JASA PENGIRIMAN PADA PT. X DENGAN PENDEKATAN HOUSE OF QUALITY. *E-Jurnal Manajemen*, 353-374.

Putra, M. D. (2019). *EKSPLORASI DEKORATIF BENTUK NAGA DENGAN TEKNIK DIGITAL DRAWING DAN LASER CUTTING PADA KAYU* . Bandung: UNIVERSITAS PENDIDIKAN INDONESIA .

Rosadi, D. (2015, November 25). *Ekspor bambu Indonesia menempati peringkat tiga dunia*. Retrieved from merdeka.com: https://www.merdeka.com/uang/ekspor-bambu-indonesia-menempati-peringkat-tiga-dunia.html

Sabhadiya, J. (2020, October 8). *What Is Machine Design?- Types, And Procedure*. Retrieved from Engineering Choice: https://www.engineeringchoice.com/what-is-machine-design-types-and-procedure/

Samboro, M. A., Sriwarno, A. B., & Djati, I. D. (2017). MATERIAL EFFICIENCY OF WOOD WASTE INDUSTRIES TO DESIGN BY USING LASER CUTTING TECHNOLOGY (PINE, SUNGKAI, SENGON, AND KAMPER WOOD). *1st ICON-ARCCADE 2017*, 240-245.

Sanny, A., & Prima, V. (2018). Pengembangan Desain Mesin Penghancur Kotoran Kambing Dengan Menggunakan Metode QFD. *Jurnal Teknologi dan Manajemen Industri*, 29-34.

Setyabudhi, A. L., & Saputra, E. (2020). ANALISIS PENGEMBANGAN PRODUK CHARGER HANDPHONE DENGAN MENGGUNAKAN METODE QUALITY FUNCTION DEPLOYMENT (QFD). *Engineering And Technology International Journal*, 150-157.

Simbolon, M. S. (2019). Daya Saing Produk Bambu Indonesia di Pasar Internasional. *UT - Forest Product Journal*.

Siregar, A. M., & Siregar, C. A. (2022). Desain Dan Pembuatan Mesin Pengaduk Srikaya Guna Membantu Meningkatkan Produktivitas Usaha Toko Roti di Kota Berastagi Sumatera Utara. *Ihsan: Jurnal Pengabdian Masyarakat*, 28-38.

Siswadi, A. N. (2021). Pengembangan Desain Mesin Opak Jepit yang Ergonomis dan Sesuai Keinginan Konsumen dengan Metode Quality Function Deployment(QFD). *TECNOSCIENZA*, 1-16.

Suartika, I. M., Alit, T., & Aprentari, F. D. (2018). PENGEMBANGAN PRODUK KURSI SUDUT PADA UKM PENGRAJINBAMBU DENGAN METODEQUALITY FUNCTION DEPLOYMENT(QFD)(Study Kasus :UD.Tiga Putri di Gunung Sari,NUSA TENGGARA BARAT). *Dinamika Teknik Mesin*, 17-23.

Suryaningrat, I. B., Mahardika, N. S., & Firlanarosa, M. E. (2021). DESAINKEMASAN SEKUNDER PADA PRODUK PROL TAPE DENGAN METODE QUALITY FUNCTION DEPLOYMENT(QFD)(Studi Kasus di UD. Purnama Jati, Kabupaten Jember). *Jurnal Agroteknologi*, 11-23.

Tatzel, L., & Leóna, F. P. (2019). Prediction of Cutting Interruptions for Laser Cutting Using Logistic Regression. *Lasers in Manufacturing Conference 2019*, 1-7.

The Plant List. (2012, March 23). *Phyllostachys aurea Rivière & C.Rivière*. Retrieved from The Plan List: http://www.theplantlist.org/tpl1.1/record/kew-434053

Thomas, D. J. (2013). The effect of laser cutting parameters on the formability of complex phase steel. *The International Journal of Advanced Manufacturing Technology*, 1297–1311.

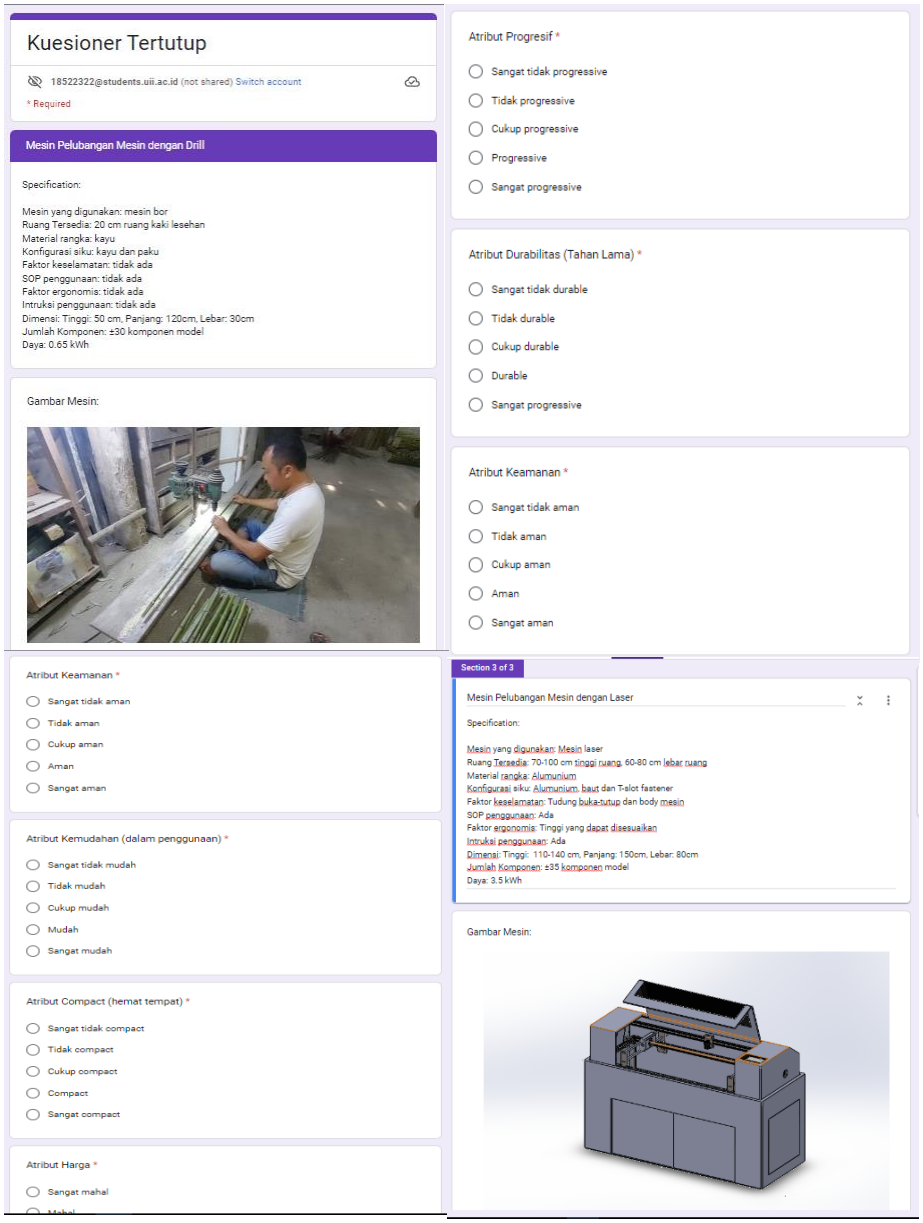
TWI Global. (2014). *LASER CUTTING - CUTTING PROCESSES*. Retrieved May 28, 2022, from TWI Global: https://www.twi-global.com/technical-knowledge/job-knowledge/cutting-processes-laser-cutting-052

Utami, E. (2018). PERANCANGAN DESAIN KEMASAN PRODUK OLAHAN COKLAT “COKADOL” DENGAN METODE QUALITY FUNCTION DEPLOYMENT. *JISI: JURNAL INTEGRASI SISTEM INDUSTRI*, 91-100.

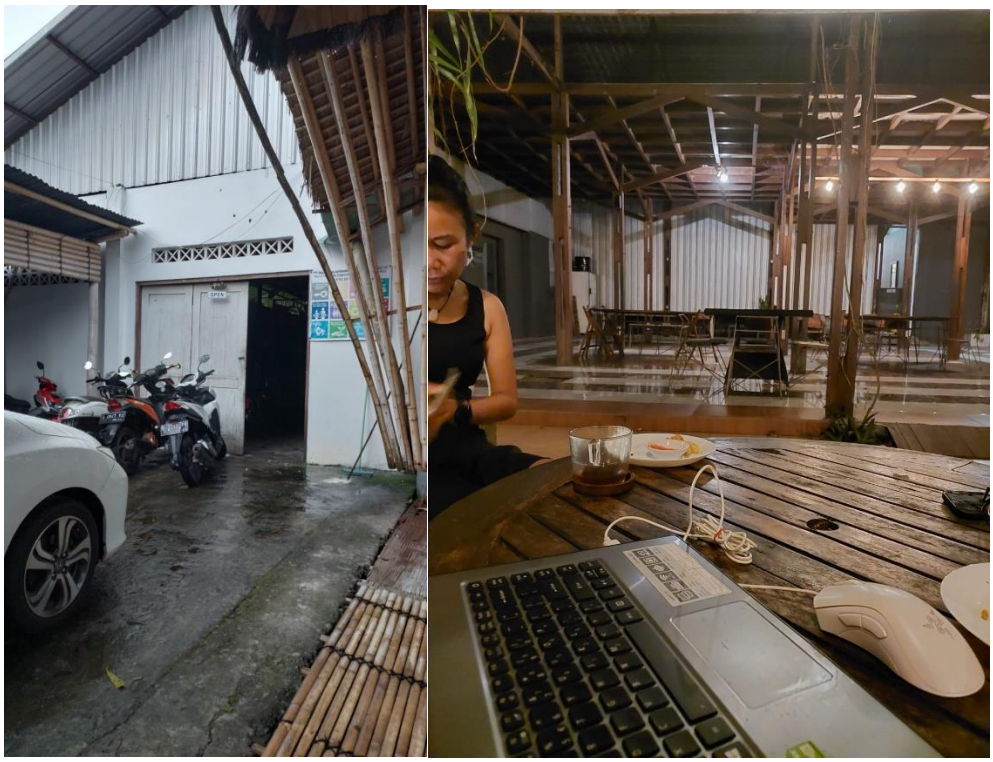
Widnyana, K. (2017). BAMBU DENGAN BERBAGAI MANFAATNYA. *Academia*.

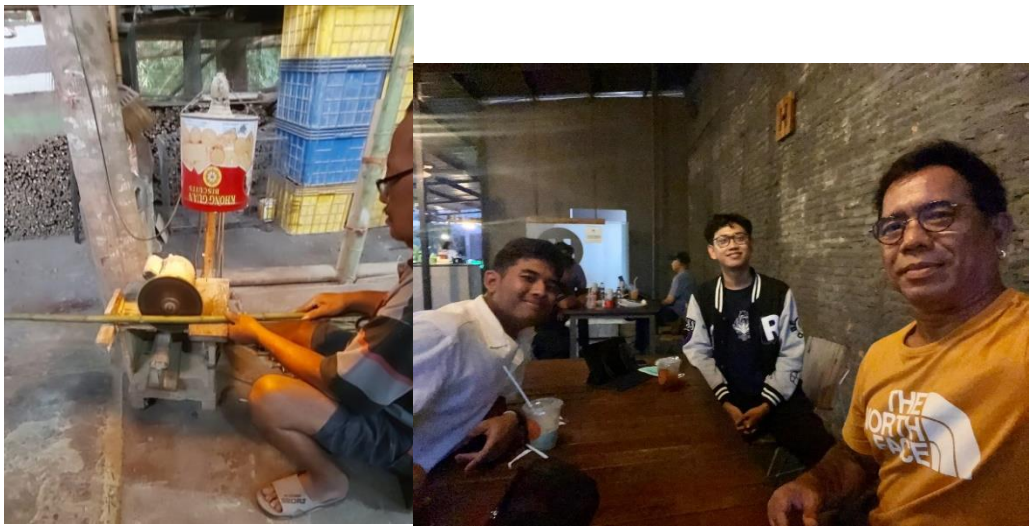
Widodo, I. D. (2005). *Perencanaan dan Pengembangan Produk (Product Planning and Design).* Yogyakarta: UII Press.

APPENDIX

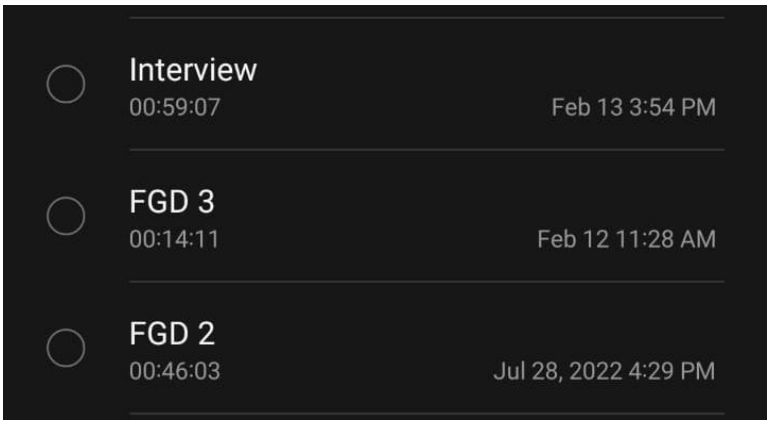


Appendix 1. Closed Questionnaire





Appendix 2. FGD and Interview Process



Appendix 3. Screenshot Record FGD and Interview