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Crushing Machine Design for Wood Waste Utilization Using Axiomatic Design Method

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ABSTRACT: The increased number of furniture orders led to a significant amount of material waste. Bahana Raya produces 5-7 m3 of multiplex and blockboard waste. Multiplex waste in the form of lumber and wood chips has been solely utilized as fuel for stoves being used for cooking for worker lunches, with the remainder simply being burned as waste. This study was carried out to provide solutions for dealing with existing waste in terms of multiplex and blockboard waste crushing machine. A tool or machine which can address all of these shortcomings were then developed. The axiomatic Design method can be utilized that can address these shortcomings workers' needs and expectations based on field conditions. Completing the stages of determining Customer Attributes (CA) and making a hierarchy of Functional Requirements (FRs) and Design Parameters (DPs) can result in a product design that meets all of the workers' needs and expectations. The result of this study suggested the development of a multiplex and blockboard waste crushing machine, which offers a number of benefits over existing wood crusher machines, including the ability to produce finer sawdust in accordance with MDF raw material criteria (0,43 g/m3).

KEYWORDS: Crushing Machine, Axiomatic Design, Waste of Multiplex, Blockboard, Medium Density Fiberboard

1. INTRODUCTION

Bahana Raya LP is a company specializing in furniture, interior designs, physical construction, interior, and exterior consultation services, graphic designs, and other housing-related services. Its vision is to provide comfortable housing at such reasonable prices that lower middle- and upper classes can make their dreams of owning a dream house come true. Bahana Raya LP produces interiors made of multiplex and blockboard as one of its business segments.

The increase in market demands is closely related to that in production. High outputs correspond to high demands, resulting in an increase in the ratio of multiplex and blockboard waste. The focus of this study is the high amount of waste and the absence of a solution to this issue that e occurred to Bahana Raya LP. This company produces 5-7 m^3 of multiplex and blockboard waste on average on a daily basis. So far, multiplex waste in the form of lumber and wood chips has solely been utilized as fuel for stoves being used to cook for workers' lunches, with the remainder simply being burned as waste.

There have so far been wood waste crushing machines [1][2], despite some drawbacks, such as the processed waste being too rough to reuse. Furthermore, the crushers used diesel-driven motors, which led to noise, air pollution, and high costs.

This study deals with the development of existing machines that can convert wood waste into sawdust, which can then be recycled into *Medium Density Fiberboard* (MDF). Furthermore, this machine produces very little noise, which then refers to the novelty of this study.

The result of this study was the design in the form of design drawings, which included machine frame drawings, driving and cutting motor drawings, stopper drawings, and photoelectric sensor drawings. It is a no-ready-to-use tool at this time. However, the technology used is outstanding for future implementation [3].

A study [4] entitled "*Product Redesign Based on Customer Requirements Integrated with Axiomatic Design and House of Quality*" sought to design a shoe rack that keeps shoes dust-free while also providing comfort. Based on the description above, a product redesign was carried out using Axiomatic Design and House of Quality integration models. The result of this study was the design of a comfortable shoe rack that keeps shoes from being dusty.

The problem addressed in a study [1] entitled "*The Design of Wood Chipping Crusher for Producing Wood Chips in Particle Board Materials Making*" was the tool design to assist the process of MDF (*Medium Density Fiberboard*) making by utilizing processing waste or furniture residue. The results of the study were presented in the form of a wood chopper calculation in terms of the number of wood choppers required to obtain chips.

According to a study entitled "*Physical Properties of Medium Density Fiberboard from Pineapple Leaf Fiber (PALF) with Cassava Peel Starch and Citric Acid*" which dealt with the adhesive commonly used in the production of MDF, derived from limited amounts of fossil fuels and has negative impacts on environment, resulting in an environmentally friendly adhesive derived from pineapple leaf fiber. The method employed was semi-chemical pulping and wet processes. The results of the study suggested that MDF has positive effects on physical properties when compared to MDF bound to cassava peel flour [5].

This waste crushing machine was discovered and designed to crush multiplex and blockboard waste into sawdust with 0,35-0,80 lg/cm^3 in size [6], which can then be used as the materials to make *Medium Density Fiberboard* (MDF) as efficient as possible as a solution to these problems.

2. RESEARCH METHODS

At this stage, the data required for the study were gathered. The data collected were Primary Data. They were gathered through interviews or questionnaires administered to relevant parties, questionnaire data for product attribute requirements required by workers, and observational data on waste characteristics of Bahana Raya company LP, observation data derived from previous wood crushers, and workers' anthropometric data. In addition, secondary data were employed to obtain information about everything done in the study, such as tool costs, related journals to support in obtaining data on the amount of production waste, and company documents related to the study. Furthermore, the obtained data were processed using *Axiomatic Design* (AD), resulting in more detailed functions and designs.

2.1 Axiomatic Design

The axiomatic Design method defines design as the creation of a synthesis solution in the form of a product, process, or system that meets the needs of customers through functional requirements (FRs) mapping in the functional domain and design parameters (DPs) in the physical domain via the selection of the appropriate DPs to satisfy the FRs [7][8]. Several customer needs were obtained from the open questionnaire results, which were then encapsulated into *customer attributes* (CA), namely domains that accommodate needs from the user's point of view. This method was divided into four domains: *customer attributes* (CA), *functional requirements* (FR), *design parameters* (DP), and *process variables* (PV).

The foundation of this design theory is the concept of *functional requirements* (FRs) and *design parameters* [9]. Referring to the technical design process as an *interplay* between what needs to be done and how it should be done. Goals are always expressed in terms of a functional domain, and then (physical solutions) are developed in terms of that functional domain. At this point, it is expected that the solutions investigated using scientific methods will be able to solve the problems, allowing further conclusions to be drawn from this study.

In *axiomatic design*, there is a hierarchy of FRs and DPs, where the former corresponds to the latter. The following is an example of the FRs and DPs hierarchy [9]

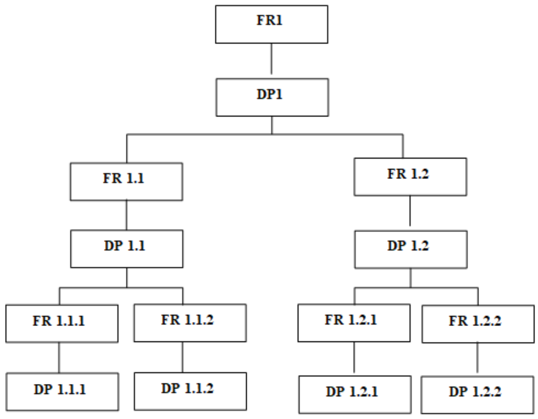


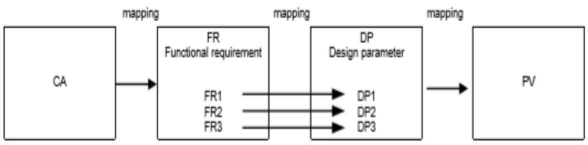
Figure 2.2 The example FRs and DPs hierarchy of Axiomatic Design [4]

The FRs and DPs hierarchy above provides visualization on the process of determining (FRs) functions and (DPs) designs based on CA (Customer Attributes) retrieved from published questionnaires. According to the above hierarchy, each product function (FRs) has its own design parameters (DPs), and each function design can be translated back to get the function and detailed design.

According to the studies [10], in summary, *axiomatic design* concept is beneficial in terms of: characterizing customer needs and expectations, recognizing or determining issues that must be overcome to meet customer needs, designing and selecting proposed solutions, analyzing and optimizing proposed solutions, as well as checking if the design results meets customer needs and expectations.

2.2. Ergonomics

Ergonomics is the study of relationships between humans and other components in a system, as well as the work that applies theories, principles, data, and methods to design an optimal system in terms of humans and their performance. Ergonomics helps to design and evaluate tasks, jobs, products, environments, and work systems so that they can be used in harmony with human needs, competences, and limitations (Purnomo, 2019).



2.3. Percentile

The majority of Anthropometric data is represented in percentile form. Percentile is a value that indicates what percentage of a group of people have dimensions that are equal to or less than that value. For instance, 95% of the population is at or below the 95-th percentile, and 5% of the population is at or below the 5-th percentile. In anthropometric data, the 95-

th percentile represents the "largest" human size, while the 5th percentile represents the "smallest" size [9]. There are two key concepts that must be understood in this percentile concept. First, individual anthropometric percentiles are based on only one body size, such as either standing or sitting height. Second, no one is referred to as being in the 90-th or 5-th percentile. It means, an individual who is in the 50-th percentile for sitting height may also be in the 40-th percentile for popliteal height or the 60-th percentile for elbow sitting height.

Table 2.1 Percentile Calculation

Percentile	Calculation
1-st	$\bar{X}$ - 2,325 $\sigma\chi$
1,5-th	$\bar{X}$ - 1,96 $\sigma\chi$
5-th	$\bar{X}$ - 1,64 $\sigma\chi$
10-th	$\bar{X}$ - 1,28 $\sigma\chi$
50-th	$\bar{X}$
90-th	$\bar{X}$ + 1,28 $\sigma\chi$
95-th	$\bar{X}$ + 1,64 $\sigma\chi$
97-th	$\bar{X}$ + 1,96 $\sigma\chi$
99-th	$\bar{X}$ + 2,325 $\sigma\chi$

(Source: [9])

2.4. Anthropometric Measurement

Anthropometric measurement includes data on shape, physical size, weight, volume, and movement space, and so on. This measurement must take into account the dimensions of human body, which are influenced by several factors such as age, gender, and occupation. This measurement is carried out on human body at rest.

3. RESULTS AND DISCUSSION

Having gathered some of the required data, such as questionnaires, anthropometric measurements, and research data, the data were then processed.

3.1 Closed Questionnaire Data Processing

The following is the result of the closed questionnaire data processing:

Table 3.1. Closed Questionnaire Recapitulation Data Processing

				Answer Statement Items							
No	**Respondent**	**Age**	Gender	**1.** Products have durable materials	**2.** The products have ergonomic sizes for workers	**3.** Products can be transferred	**4.** Products are safe	**5.** The products have press on the hopper	**6.** The products have a speed controller in the form of a display screen	**7.** The products have a sack hook on the output hole	**8.**The resulting output is in the form of powder
1	Respondent 1	39	Male	4	4	3	4	3	3	4	4
2	Respondent 2	36	Male	4	4	3	4	3	4	4	4
3	Respondent 3	35	Male	4 l	4	3	4	3	3	4	4
4	Respondent 4	41	Male	4	3	3	4	3	3	4	4
5	Respondent 5	31	Male	4	4	4	4	3	3	4	4
6	Respondent 6	45	Male	3	4	4	4	3	3	3	4
7	Respondent 7	39	Male	4	4	3	4	4	4	3	4
8	Respondent 8	44	Male	4	4	3	4	3	4	4	4
Total				31	31	26	32	25	27	30	32

No	Respondents	Age	Sex	Responses of Statement Items							
				1. The product is made of durable materials.	**2.** The product is ergonomically in size for workers.	**3.** The product is movable	**4.** The product is safe	**5.** The product has a suppressor on the hopper	**6.** The product has a speed controller in the form of display screen	**7.** The product has a bag hook on the output port	**8.** The final output is in the form of sawdust
1	Respondent 1	39	Male	4	4	3	4	3	3	4	4
2	Respondent 2	36	Male	4	4	3	4	3	4	4	4
3	Respondent 3	35	Male	4 l	4	3	4	3	3	4	4
4	Respondent 4	41	Male	4	3	3	4	3	3	4	4
5	Respondent 5	31	Male	4	4	4	4	3	3	4	4
6	Respondent 6	45	Male	3	4	4	4	3	3	3	4
7	Respondent 7	39	Male	4	4	3	4	4	4	3	4
8	Respondent 8	44	Male	4	4	3	4	3	4	4	4
Total				31	31	26	32	25	27	30	32

In processing closed questionnaire data recapitulation, from 8 correspondents who completed the questionnaires, the results were obtained with an average response of "agree" and "strongly agree", where "agree" is valued 3 and "strongly agree" is 4. After all results were grouped into one and processed or calculated using the *excel* application, the calculation results were obtained as follows: “Question 1: 31, Question 2: 31, Question 3: 26, Question 4: 32, Question 5: 25, Question 6: 27, Question 7: 30", Question 8: 32. According to the results of closed questionnaire recapitulation, the eight attributes listed above were included in their entirety, since all respondents' responses in the closed questionnaire were “agree”, and “strongly agree”.

Based on the closed questionnaire processing, all attributes were used, because the respondents’ responses were “agree” and “strongly agree” on the closed questionnaire statement items. The recapitulation results in table 4.8 were taken from closed questionnaire data that have been distributed and received values 4 (strongly agree) and 3. (agree). The followings are the results of the closed questionnaire attributes that received agree and strongly agree responses:

Table 3.2 Closed Questionnaire Recapitulation Data Processing

No.	Closed Questionnaire Recapitulation Results
1.	The product is made of durable materials
2.	The product is ergonomically in size
3.	The product is movable
4.	The product is safe
5.	The product has a waste suppressor on the hopper
6.	The product has a speed controller
7.	The product has a bag hook on the output channel
8.	The final output is in the form of sawdust

3.2 Functional Requirements (FRs) and Design Parameters (DPs) Mapping

The *Axiomatic Design* (AD) method was employed to elaborate on the 8 *Customer Attributes* (CA) that have been obtained. At the *Functional requirements* (FRs) and *Design Parameters* (DPs) stages, the final design specifications, which can be developed into a multiplex and blockboard crusher, were then obtained. The table below shows the method of *functional requirements* (FRs) and *design parameters* (DPs) mapping:

Tabel 3.3. FRs and DPs Mapping

Code	*Customer Atribute* (CA)	Code	*Functional Requirements* (FRs)	Code	*Design Parameters* (DPs)
CA 1	The product is made of durable materials	FR 1	The product is developed using durable materials	DP 1	Using sturdy and sustainable components
		FR 1.1	The product uses strong and sturdy materials	DP 1.1	5 cm UNP iron frame material and iron plate for the machine chasing
		FR 1.1.1	The product uses rust-resistant paint on iron	DP 1.1.1	Green-colored painting for chasing
		FR 1.1.2	Using driving motor	DP 1.1.2	Electric motor 3 HP, 3 phase, 1420 rpm
		FR 1.1.3	Using other materials	DP 1.1.3	V-belts, 7 inch and 9 inch pulleys, bearings, nuts, bolts, wire, welding
CA 2	Ergonomic	FR 2	Providing comfortable machine dimensions when used	DP 2	Machine design is based on worker anthropometric data
		FR 2.1	Design of the machine frame height	DP 2.1	Body dimensions in standing waist height
		FR 2.1.1	The 50-th percentile is equated with standing waist height	DP 2.1.1	89,1 cm is equated with 90 cm in the product size
		FR 2.2	Design of hopper to user distance	DP 2.2	Body dimensions is equated with hands forward reach
		FR 2.2.1	The 50-th percentile is equated with hands forward reach	DP 2.2.1	66,1 cm is equated with 40 cm in the product size
		FR 2.3	Design of hopper width and machine transporting handle	DP 2.3	Body dimension is equated with little thumb width
		FR 2.3.1	The 50-th percentile is equated with little thumb width	DP 2.3.1	14,7 cm is equated with 15 cm in the product size
		FR 2.4	Design of machine's maximum height	DP 2.4	Body dimension is equated with standing eye height
		FR 2.4.1	The 50-th percentile is equated with standing eye height	DP 2.4.1	55,4 cm is equated with 114 cm in the product size
		FR 2.5	Design of moving handheld grip height	DP 2.5	Maximum grip diameter dimension
		FR 2.5.1	The 50-th percentile of maximum grip diameter	DP 2.5.1	3,2 cm is equated with 3 cm in the product size
	The product is movable	FR 3	The product is developed to be easily moved to the desired location	DP 3	There are 2 wheels located at the corners of the right side of the machine base

CA 3		FR 3.1	The wheels used are not easily damaged	DP 3.1	The material used is made of iron wheels
		FR 3.1.1	The wheels are driven manually	DP 3.1.1	The wheels can be moved manually
		FR 3.1.2	There is a pull handheld to move the machine easily	DP 3.1.2	The handheld is rectangular iron on the left side of the machine
CA 4	The product is safe	FR 4	The product is developed with sturdy frame, chasing density, and installation accuracy	DP 4	The product is designed with sturdy frame and chasing density as well as accuracy in assembling
		FR 4.1	The product has strong and sturdy basic materials	DP 4.1	Using all kinds of iron and steel materials, so it is strong and safe
		FR 4.1.1	Using strong iron material and covering the body elbows	DP 4.1.1	Using a 5 cm UNP iron frame
		FR 4.1.2	Using chasing materials that are thick and leaving no hollow	DP 4.1.2	Using a 3mm steel plate
		FR 4.2	Determining supporting materials	DP 4.2	Using safe materials which strengthen the structure of the machine
		FR 4.2.1	Supporting materials	DP 4.2.1	Elbow glue, nuts, bolts, paint to minimize rust
CA 5	The product has a waste suppressor on the hopper	FR 5	The product is developed with a waste suppressor in the hopper	DP 5	The waste suppressor on the hopper is in the form of a movable lever
		FR 5.1	Helping users suppress waste until it is grated, making it safer	DP 5.1	The suppressor size adjusts to of the hopper width: 15 cm
		FR 5.1.1	The suppressor is designed to make it easier for the user thus more effective	DP 5.1.1	The suppressor employs the push method in conjunction with an intermediary lever
		FR 5.1.2	The operation is done manually	DP 5.1.2	The operation is done manually using a lever
CA 6	The product has a speed controller	FR 6	The machine’s rotational speed can be adjusted as needed.	DP 6	Controlling the machine’s rotational speed with inventor and arduino uno
		FR 6.1	Using a variable-speed motor	DP 6.1	Using an electric motor (non-diesel)
		FR 6.1.1	Determining the driving motor	DP 6.1.1	Electric motor 3 HP, 3 phase, 1420 rpm
		FR 6.2	Control can be done through display	DP 6.2	Using a monitor-based 20 x 4 display
		FR 6.2.1	Easily accessible display placement	DP 6.2.1	Display is placed on the left of the hopper
		FR 6.2.2	The options box with a clear text and a bright color	DP 6.2.2	Using moderate fonts in black and white to easily read
		FR 6.2.3	There is a manual for display operation	DP 6.2.3	The operation manual is placed next to the display
CA 7	The product has a bag hook on the output channel	FR l7	The developed product has a port bracket with an adjustable output channel size	DP l7	The hook is placed on the output channel's front and back sides

		FR 7.1	The hook is designed to secure the bag position at the output channel	DP 7.1	As a lock, a sharp-shaped hook is stabbed into the tip of the bag
		FR 7.1.1	The hook's height is adjusted to the overall height of the bag	DP 7.1.1	The height of hook transmitting to bag: 52 cm
		FR 7.2	It is designed to facilitate output transmission to bag	DP 7.2	The output channel edge is rectangular in size
		FR 7.2.1	In general, the height of the output channel's edge is adjusted to the size of the bag height	DP 7.2.1	The height of Output channel edge: 50
CA 8	The final output is in the form of sawdust	FR 8	The developed product contains a crushing blade capable of producing powder	DP 8	The chopping method is done using grating system
		FR 8.1	The materials used are so solid that won't be damaged	DP 8.1	Using an 8 mm iron plate with a diameter of 45 cm
		FR 8.1.1	The grated knife used can perfectly crush the waste	DP 8.1.1	Using 1097 pieces of grated gears attached to an iron plate, with a steel/concrete base material with dimensions d: 4 p: l10 mm
		FR 8.2	The grating resulted is in the form of sawdust that can be utilized as an MDF base material.	DP 8.2	The resulted sawdust has a fineness level of l0.35-0.80 lg/cm^3
		FR 8.2.1	It has a sawdust filter on the machine according to the standard level of fineness required	DP 8.2.1	Using a 14 x 14 cm iron plate, the filter is placed at the entrance to the output channel

3.3 Anthropometric Measurement Results with Percentiles

The following are the results of anthropometric measurements with the percentile calculation 5; 50; 99 manually derived from the dimensions of the worker's body that has been carried out in order to adjust to the size of the tool to be made.

Table 3.4. Anthropometric Measurement Results

No.	Anthropometric Dimensions	Average (cm)	Product Information	The 50th Percentile (cm)	*Alloweence (cm)*	Product Size (cm)
1	Hands Forward Reach	66,1	The distance between hopper and user	66,1	26,1	40
2.	Standing Waist Height	89,1	Machine frame height	89,1	,9	90
3.	Little Thumb Distance	14,7	Hopper width and moving holder	15	,3	15
4.	Standing Eye Height	155,4	Maximum limit of total machine height	155,4	41,4	114
5.	Maximum Grip Diameter	3,2	grip width of moving machine	3,2	0,2	3

Table 3.5. Measurement Results of Object Dimensions

No	Object Dimension	Object Size	Product Information	Product Size
1.	Bag Height 10 Kg	55 cm	The distance between output channel edge and iron plate base	52 cm
2.	Waste Height	9 mm– 18 mm	Minimum height of hopper port	8 cm

The 50-th percentile was determined since all workers measured were indeed prospective users of multiplex and blockboard crushing machines at Bahana Raya LP. Whereas, table 4.14 is a table of object dimensions that serves as the foundation for product measurements.

3.4 Design of Multiplex and Blockboard Crusher

After characterizing the needs and expectations of interior workers of Bahana Raya LP, the forming attributes or *Customer Attributes* (CA) were obtained as functions and specifications of the tool or product design to be made, along with *Functional Requirements* (FRs) and *Design Parameters* (DPs). Following that, body measurements were conducted for all prospective user workers so that they could be adjusted to fit the anthropometric measurements. Figure 4.4 below is the design form of a waste crusher based on Customer Attributes (CA) that have been processed using FRs Hierarchy Plans or product-forming attributes that suit the workers' needs, and are in accordance with the dimensions of the workers' bodies:

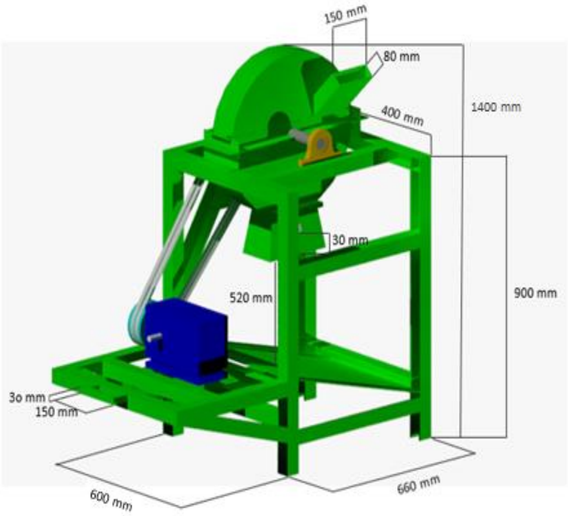


Figure 3.1 The Design of Multiplex and Blockboard Waste Crusher

3.5 Implementation

The following is the implementation of the multiplex and blockboard waste crusher that has been developed:

Figure 3.2 Multiplex and blockboard waste crusher

3.6 Comparison of Old and Newly-Developed Machines

The following is a comparison of Old and Newly-Developed Machines.

Table 3.6. Comparison of Old and Newly Developed Machines

Old Machines	Newly Developed Machines
Using a diesel-driven motor	Using an electrical induction-driven motor
Producing noise and smoke generated from diesel fuel	Producing no noise and smoke coming from the induction motor
Using a chopping method using chopping knives	Using a grating method with knife-based disc graters
The chopping results are in the form of small pieces (not smooth)	The grating results take form of finer sawdust than those of previous machines
The procedures for loading objects into the chopper are done manually.	The procedures for loading objects into the chopper are done using lever
The market rate is more than 10 million rupiahs	The cost is cheaper at 4.3 million rupiahs

Figure 3.3 The sawdust result of previous machine sawdust and that of the latest machine

4 CONCLUSION

The density of the output produced by the multiplex and blockboard waste crushing machine is 0,43 g/cm3, which meets the density requirements of the JIS A 5905-2003 standard MDF sawdust (0,35-0,80 g/cm3). This machine is driven by an induction electric motor, which produces no noise or smoke and is very efficient. It uses a knife-based disc grater and grating method. In addition, it can produce finer sawdust output than previous machines by using less power (HP) and speed (rpm).

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