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Research Article

Axiomatic Design for Redesign of the Mucuna Slicing Machine

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Abstract: Machine redesign was now very important to solve existing design problems and adapt production flows to the development of industrial needs. One of the medium-sized industries that uses machines for its production is the Tempe Chips Industrial Center located in Grobog Village, Wonogiri District. The slicing machine currently used by the Tempe Chips Industrial Center located in Grobog Village, Wonogiri District often produces unstable cuts and a lot of waste. This study aims to present the Axiomatic Design (AD) model as a structured framework for redesigning a high-quality slicing machine. The Axiomatic Design method was used to translate customer needs (Voice of Customer) and environmental criteria (Voice of Environment) into Functional Requirements (FRs). FRs were then used as the main input in developing Design Parameters (DPs), resulting in a Design Matrix. The design results that the proposed design has two blades with a thickness of 2 mm, a 1/4 Hp dynamo, which requires an adjustment to the target capacity of ±10 kg/hour, dimensions of machine had 300 mm in length, 250 mm in width, and 399 mm in height. Axiomatic Design can be effectively applied as a framework for redesigning medium-scale industrial food processing machines, especially for Mucuna commodities, a relatively hard commodity that demands cutting precision. Further research was recommended to develop this design result to the detailed design and prototyping stage.

Keywords: Axiomatic-Design; Optimalization; Productivities; Redesign; Slicing-Machine.

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1. Introduction

The manufacturing industry in Indonesia continues to race against the need for efficient and competitive production equipment. In industrial sectors involving high-precision raw material processing, such as manufacturing, machine performance is a crucial element influencing product quality and operational effectiveness (Kurniawan, et al., 2024) (Siswadi & Nugroho, 2021). Many of the machine tools used in manufacturing and small and medium-sized enterprises (SMEs) are generally older models, and they suffer from a number of shortcomings. For example, unstable production output, high levels of waste, and inefficient energy use are still common (Siswadi & Nugroho, 2021), where this has a direct impact on the product's profitability and competitive position (Lapinskiene & Motuziene, 2021).

Machine redesign is now very important to solve existing design problems and adapt production flows to the development of industrial needs (Arkouli, et al., 2024).

One medium-sized industry that uses machines for its production is the Tempe Chips Industry Center, located in Grobog Village, Wonogiri District. The Tempe Chips Industry Center, located in Grobog Village, Wonogiri District, uses machines for the production process of slicing Mucuna. The chip-making process, over time and the intensity of use of the Mucuna slicing machine, has encountered several obstacles that directly impact the final product (Agusti, et al., 2022). The results of field observations that have been carried out show several problems, namely: the previous design did not provide convenience for users for the maintenance process, even though maintenance is needed to maintain the machine so that it lasts and facilitates the production process. Furthermore, the previous design had a shape that was less easy to disassemble for cleaning, even though this machine was used in food production which often had to be disassembled for cleaning. The design of the machine had an inappropriate output funnel design because the output from the slicing results came out as far as ± 1 meter, besides that it also had many angles so that the sliced results often got stuck and then caused other sliced results to be damaged. In addition, the previous machine design did not take into account environmental aspects, such as the type of material, the amount of material used, and energy consumption.

Many of the machine tools used in small and medium-sized enterprises (SMEs) are generally outdated models, with a number of shortcomings. Product design is the process of transforming ideas, business owner desires, and customer expectations into tangible products. Processes such as product development, form design, functional design, packaging design, and product research all explain the specific meaning of product design (Arkouli, et al., 2024) (Verma, et al., 2020) (Ishak, et al., 2024). One of the redesign methods that can be used is Axiomatic Design.

Axiomatic Design (AD) offers a structured framework to ensure the implementation of design solutions in the most efficient manner (Chenio, et al., 2025) (Yazid, et al., 2024). Axiomatic Design (AD), through the principle of independence, provides guidance to designers on establishing a one-to-one relationship between functional requirements (FRs) and design parameters (DPs). This is crucial for producing a robust, maintainable design that avoids design overlaps that can lead to complexity (Yazid, et al., 2024). Research conducted at the national level indicates that the integration of design techniques is a critical factor in the overall product development process. For example, it has been shown that combining Axiomatic Design (AD) with other approaches can increase design effectiveness and reduce costs (Chenio, et al., 2025) (Kittichotsatsawat, et al., 2024). Axiomatic Design method to transform consumer needs data into desired designs (Liu, et al., 2023) (Fazeli & Peng, 2022). Two axiom designs are used in the Axiomatic Design method which is useful for designing satisfactory products (Feng & Chen, 2025).

Based on previous research and the problems experienced by medium-sized industries (MSMEs), it can be concluded that most studies focus on improving partial performance such as capacity, quality, or ergonomics separately. However, there are still limitations in the application of systematic and integrated design methods to ensure independence between design functions and minimize overall system complexity. Therefore, this study fills this gap by comprehensively applying Axiomatic Design to the redesign of the Mucuna slicing machine tailored to the real needs of the medium-sized industry.

2. Literature Review

This research uses a quantitative descriptive method that emphasizes structured system design, utilizing the environmentally friendly integrity of Axiomatic Design (AD). Axiomatic Design (AD) uses axioms in the design process, including (Feng & Chen, 2025) These are: Axiom 1: the independence axiom (maintaining the independence of functional requirements). Axiom 2: the information axiom (minimizing the information content of the design). The axiom process can be described as a domain design process as in Fig. 1. Furthermore, the literature review phase focused on relevant previous research. Previous research can be seen in Table 1.

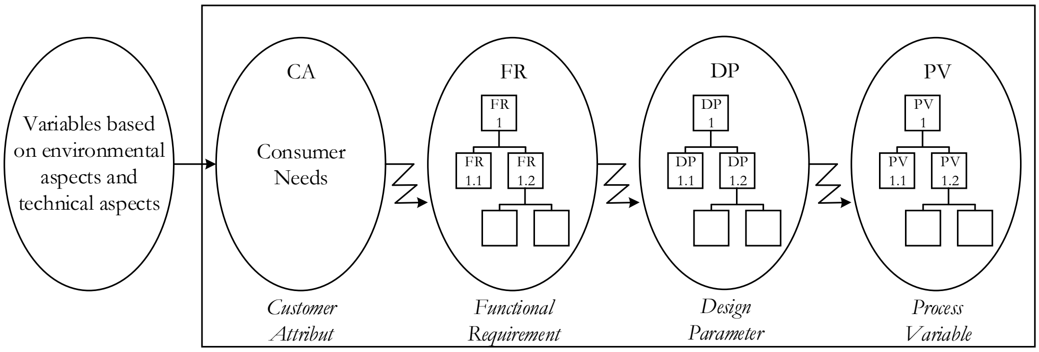

Figure 1. Domain design process.

Tabel 1. Previous research.

No	Research Gap	Author
1	Hierarchical Design Analysis: Applied Axiomatic Design to hierarchically analyze tractor powertrain architecture and develop a design matrix, which was further transformed into a coupling contradiction matrix. Performance Validation: Simulation and prototype experiments confirmed that the distributed hybrid electric tractor design improved energy efficiency and reduced emissions.	(Li, et al., 2022)
2	Improved Machine Performance: Redesign introduced additional design parameters to achieve functional independence, enabling independent control of separation and washing processes and increasing production rate by 20–30%. Decoupled Design Strategy: Demonstrated the effectiveness of transforming coupled designs into decoupled or uncoupled designs using Axiomatic Design to enhance efficiency and productivity.	(Santos, et al., 2022)
3	Case Study Validation: A water dispenser case study showed that the proposed Axiomatic Design-based methodology produced a superior design compared to existing models. Structured Design Framework: Confirmed that Axiomatic Design provides a systematic, analytical framework that minimizes reliance on trial-and-error approaches.	(Adilah, et al., 2023)
4	Enhanced Detachability: Applied a Kano–AD–DSM-based strategy to identify five functional modules of a micro-tiller, significantly improving disassembly and remanufacturing performance. Functional Decomposition: Employed Z-mapping to decompose user demands into functions and structures, establishing a design matrix for parameter.	(Zhou, et al., 2024)
5	Industrial Case Studies: Reported two industrial applications of Axiomatic Design for semi-automated and fully automated assembly systems. Technology Selection: Used Axiomatic Design to evaluate and select optimal technologies, improving ergonomics and reducing cycle time.	(Merati, et al., 2021)

3. Method

The research process is divided into six important phases: Identification of Problems and User Needs, Determination of Customer Attributes (CA), Formulation of Functional Requirements (FR) and Constraints (C), Determination of Design Parameters (DP), Preparation and Analysis of Design Matrix, Detailed Machine Design (Detail Design). The complete research phases can be seen in Fig. 2. The research stages are as follows:

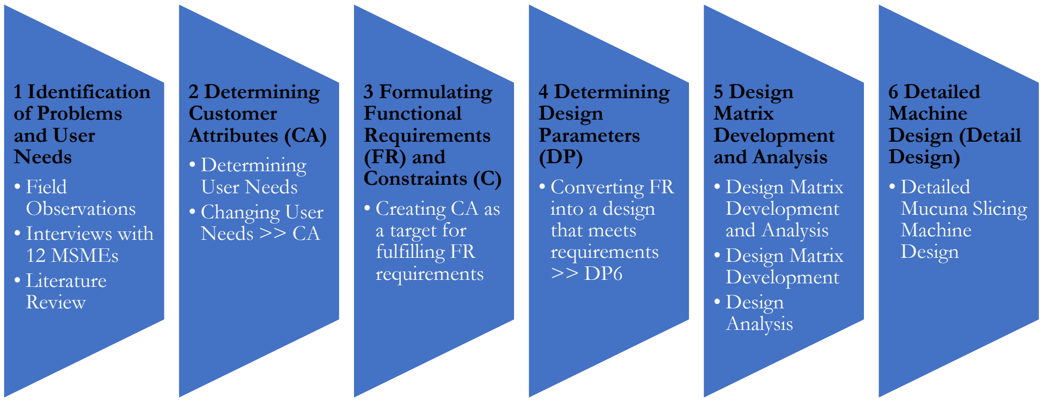

Figure 2. Research stage.

First Stage: Identifying Problems and User Needs

The first stage of this research was to identify the problems and user needs of the Mucuna slicing machine currently used by medium-sized enterprises (MSMEs). The main problems identified included uneven slice thickness, low slicing capacity, high machine vibration levels during operation, and suboptimal ergonomics and safety. Furthermore, the quality of the slices produced by the existing machine did not fully meet the specifications required by medium-sized enterprises, particularly regarding consistency of size and final product quality.

This stage also collected technical and operational data on the existing Mucuna slicing machine, including machine specifications, workflow and processes, production capacity, processing time, slice quality, and various complaints reported by operators during machine use. This data was used as a basis for understanding the actual condition of the machine and identifying the root causes of problems encountered in the field.

The problem identification phase was conducted through direct field observations and in-depth interviews with 12 medium-sized enterprises (MSMEs) in the Tempe Chips Industry Center located in Grobog Village, Wonogiri District. Field observations and interviews aimed to capture real user needs and operational issues of the machine, while a literature review was used to obtain an overview of the development and redesign of slicing machines for similar commodities, the design approaches that have been applied, as well as the weaknesses and opportunities for machine development.

Second Stage: Determining Customer Attributes (CA)

The second stage aims to determine Customer Attributes (CA) as a representation of the needs and expectations of Mucuna slicing machine users. Customer attributes are obtained by translating the variables resulting from the problem identification stage and user needs into more structured and measurable technical language. This process is carried out to ensure that all user needs are systematically accommodated in the design phase. Based on field observations, interviews with small and medium-sized enterprises (SMEs), and literature review, several key customer attributes were identified that were the focus of the redesign of the Mucuna slicing machine. These customer attributes include high cutting efficiency, uniform slice thickness, ease of machine operation, adequate work safety, ease of maintenance and repair, and low operational costs. Each of these customer attributes reflects the functional and non-functional needs of users, which will form the basis for formulating functional requirements (Garrido, et al., 2023) (Flores, et al., 2022).

Third Stage: Formulating Functional Requirements (FR) and Constraints (C)

The third stage aims to formulate the primary and derived Functional Requirements (FR) that must be met by the redesigned Mucuna slicing machine. Functional requirements are established based on the customer attributes determined in the previous stage, so that each formulated function directly represents user needs in a measurable and independent manner. Constraints (C) are also established at this stage as design limitations that must be met, including machine dimensions that are suitable for medium-sized industrial workspace conditions, the selection of food-safe materials with adequate wear resistance, compliance with operator safety standards, and cost limitations adjusted to the investment capabilities of medium-sized industrial enterprises. Establishing these constraints aims to ensure that the machine design is not only functionally optimal but also technically, economically, and operationally feasible.

Fourth Stage: Determining Design Parameters (DP)

The fourth stage is carried out to establish Design Parameters (DP) that are capable of meeting each Functional Requirement (FR) formulated in the previous stage. Design parameters are determined systematically, considering the relationship between the required function and the proposed design solution, so that each DP can represent a single FR clearly and measurably.

The established design parameters cover several key aspects, namely the design of the cutting blade, cutting mechanism, power transmission system, machine frame, and safety system. Each design parameter is selected by considering cutting performance, machine stability and reliability, ease of operation and maintenance, and operator safety. The DP alternatives generated at this stage are then used to develop a design matrix to evaluate the degree of interrelationship between FR and DP based on Axiomatic Design principles (Cavique, 2022) (Assawarungsri, 2023).

Fifth Stage: Design Matrix Compilation and Analysis

The fifth stage involves compiling a design matrix that represents the relationship between Functional Requirements (FR) and Design Parameters (DP). The design matrix is used to illustrate the level of interrelationship and influence of each DP on the corresponding FR, allowing for systematic analysis of the machine design structure. The design matrix analysis is conducted based on the Independence Axiom, with the aim of ensuring that each functional requirement can be met independently by the specified design parameters. Through this analysis, the design structure is evaluated to determine whether it is uncoupled, decoupled, or coupled. If a coupled relationship is found, adjustments or reformulation of the design parameters are made to minimize the interrelationships between functions. The results of this stage serve as the basis for selecting the most optimal design before evaluation using the Information Axiom (Edward, et al., 2023).

Sixth Stage: Detailed Machine Design

The sixth stage is the development of the selected design into a detailed design for the redesigned Mucuna slicing machine. At this stage, the conceptual design, which meets Axiomatic Design principles, is developed into complete technical specifications ready for implementation. Detailed design includes creating engineering drawings for each machine component, determining dimensions and tolerances, selecting materials that meet food safety and mechanical durability standards, and designing the overall machine's operating mechanism. Furthermore, specifications for supporting components such as the transmission system, machine frame, and safety devices are determined. The output of this stage is a technical document that serves as a reference in the manufacturing process and performance evaluation of the redesigned Mucuna slicing machine.

4. Results and Discussion

Identification of Consumer Needs and Customer Attributes (CA)

The problem identification phase was conducted through direct field observations and in-depth interviews with 12 medium-sized enterprises (MSMEs) in the Tempe Chips Industry Center located in Grobog Village, Wonogiri District. The field observations and interviews aimed to capture the actual needs of users and the operational issues with the slicing machine. This Micro, Small, and Medium Enterprise (MSME) in Grobog Village, Wonogiri District, can produce nearly 30 kg of Mucuna in each production session. The production process begins with washing the Mucuna, boiling it, soaking it, slicing it, fermenting the Mucuna tempeh, molding the Mucuna tempeh, frying the Mucuna tempeh, packaging, and distributing the Mucuna tempeh chips. The slicing process uses a slicing machine, while the rest of the process is still done manually. However, with increased use, some of the pieces produced by the machine often break and become flakes. The need for a Mucuna slicing machine is shown in Table 2.

Table 2. Questionnaire Results into Customer Attributes (CA).

No	Consumer Needs	Customer Attributes (CA)	Indicator Size
1	Higher slicing productivity	High cutting productivity	Production capacity (kg/hour), Processing time per unit of product (seconds/kg)
2	Slice thickness must be equal and thin	Uniformity and precision of slice thickness	Average slice thickness (mm), Percentage of slices according to specifications (%)
3	Ease of machine operation	Sase and comfort of machine operation	Machine setup and adjustment time (minutes), Number of operating steps, Ease of use score (operator questionnaire)
4	Safe operation of the machine	Operator safety and security	Number of potential hazards identified, Availability of guards and safety systems
5	Easy maintenance and repair	Ease of machine maintenance and repair	Routine maintenance time (minutes), Number of removable components (modularity), Failure rate
6	Low machine operating costs	Efficient machine operating costs	Energy consumption (kWh/kg of product), Operating costs per kg of product (Rp/kg)

Based on the information contained in questionnaire A in Table 2, it is explained that respondents were interested in improving the Mucuna slicing machine. The data from questionnaire A was then converted into consumer needs, which were then used to create indicators to assess machine efficiency.

Formulating Customer Attributes (CA) into Functional Requirements (FR)

Customer Attributes (CA) derived from user needs are then translated into Functional Requirements (FR) to ensure that each user requirement is represented functionally and independently. Table 3. Represents the process of converting Customer Attributes (CA) into Functional Requirements (FR).

Table 3. Customer Attributes (CA) into Functional Requirements (FR).

No	Customer Attributes (CA)	Functional Requirements (FR1)	Functional Requirements (FR2)
1	CA1: High cutting productivity	FR1.1: Increase machine cutting capacity	FR1.1.1: Accelerate cutting rate FR1.1.2: Minimize machine downtime
2	CA2: Uniformity and precision of slice thickness	FR1.2: Produce uniform and precise slice thickness	FR1.2.1: Maintain material stability FR1.2.2: Maintain consistent blade clearance
3	CA3: Ease and comfort of machine operation	FR1.3: Simplify machine operation and setup	FR1.3.1: implify control system FR1.3.2: Reduce operator workload
4	CA4: Operator safety and security	FR1.4: nsure operator safety during operation	FR1.4.1: Prevent direct operator contact with the blade FR1.4.2: Reduce vibration and noise risks
5	CA5: Ease of machine maintenance and repair	FR1.5: Simplify machine maintenance and repair	FR1.5.1: Simplify component removal and installation FR1.5.2: Reduce component failure rates
6	CA6: Efficient machine operating costs	FR1.6: Reduce machine operating costs	FR1.6.1: Reduce energy consumption FR1.6.2: Reduce maintenance and spare parts costs

Formulating Functional Requirements (FR) into Design Parameters (DP)

The formulated Functional Requirements (FR) are then translated into Design Parameters (DP) as technical solutions to fulfill each defined function. DP determination is carried out by ensuring that each DP specifically fulfills one FR and minimizing interrelationships between functions in accordance with the Independence Axiom in Axiomatic Design. Table 4 shows the process of converting Customer Attributes (CA) into Functional Requirements (FR).

Table 4. Customer Attributes (CA) into Functional Requirements (FR).

No	Functional Requirements (FR1)	Design Parameters (DP1)	Design Parameters (DP2)
1	FR1.1: Increase machine cutting capacity	DP1.1: Optimal cutting speed mechanism	DP1.1.1 Variable speed rotating blade DP1.1.2 Simple and reliable transmission system
2	FR1.2: Produce uniform and precise slice thickness	DP1.2: Simple and reliable transmission system	DP1.2.1 Material holding and guiding mechanism DP1.2.2 Precision thread-based thickness adjustment system
3	FR1.3: Simplify machine operation and setup	DP1.3: Simple and ergonomic operating interface	DP1.3.1 Simple mechanical switches and controls

			DP1.3.2 Ergonomic working height and position
4	FR1.4: nsure operator safety during operation	DP1.4: Integrated machine guard and safety system	DP1.4.1 Knife guard and transmission cover DP1.4.2 Rigid machine frame with vibration damping
5	FR1.5: Simplify machine maintenance and repair	DP1.5: Modular design of machine components	DP1.5.1 Standard bolted and quick-release connections DP1.5.2 Wear- and corrosion-resistant materials
6	FR1.6: Reduce machine operating costs	DP1.6: Energy-efficient drive and transmission system	DP1.6.1 High-efficiency electric motor DP1.6.2 Easily available standard components

Product Design Matrix

The next stage in this research was the development of a design matrix and the development of a preliminary design for the Mucuna slicing machine. At this stage, each Functional Requirement (FR) was directly linked to a Design Parameter (DP) at a predetermined hierarchical level. In accordance with Axiomatic Design principles, each FR must be met by at least one relevant DP, with the goal of maintaining functional independence and minimizing interrelationships between functions. The design matrix results are presented in Table 5. The FR–DP mapping results presented in Table 5 can be explained as follows:

FR1 – Increasing production capacity is achieved by DP1, which uses a dual-blade knife disc. This configuration allows for an increased number of slices per unit time, allowing for increased machine production capacity without increasing the complexity of the cutting system.

FR2 – Slice thickness uniformity (±2 mm) is achieved by DP2, a blade disc equipped with a slice thickness adjustment mechanism. This adjustment mechanism allows the operator to adjust the thickness precisely and consistently, ensuring that the resulting slices meet the specifications required by medium-sized industries.

FR3 – DP3 meets the machine's dimensions and ensures ease of operation, with dimensions of 300 mm in length, 250 mm in width, and 399 mm in height. These dimensions are adjusted based on the operator's anthropometric data to ensure the machine is ergonomically designed. Furthermore, the machine is equipped with an automatic on/off switch to enhance ease and safety of operation.

FR4 – DP4 ensures safety and comfort, featuring a solid stainless steel machine frame cover. This cover protects moving components and enhances hygiene, ensuring the machine is safe and comfortable to use in food processing.

FR5 – DP5 ensures ease of maintenance and repair, incorporating a key system for keying and disassembly on the machine's main components. This design allows for faster and more efficient maintenance and repairs without the need for specialized equipment.

FR6 – Achieving a cutting capacity of approximately 10 kg/hour with low operating costs is achieved by DP6, which utilizes a ¼ HP electric dynamo with a shaft rotation of 1400 rpm, a voltage of 110/220 V, and a single transmission system using a V-belt. These specifications were selected to balance engine performance, energy efficiency, and component availability.

Overall, the design matrix analysis results indicate that each FR has a dominant relationship with one primary DP, resulting in a decoupled design structure. This indicates that the Axiom of Independence has been met, where changes to one design parameter do not significantly impact the fulfillment of other functions. Therefore, the initial design of the proposed Mucuna slicing machine is deemed feasible to proceed to the detailed design and performance testing stages.

Table 5. Matriks desain produk.

FRs/DPs	DP1	DP2	DP3	DP4	DP5	DP6
FR1	1	0	0	0	0	0
FR2	0	1	0	0	0	0
FR3	0	0	1	0	0	0
FR4	0	0	0	1	0	0
FR5	0	0	0	0	1	0
FR6	0	0	0	0	0	1

Mucuna Slicing Machine Redesign

The next stage in this research was the development of an engineering design for the Mucuna slicing machine based on the design parameters established in the previous stage. The redesign process was conducted using SolidWorks software to produce a three-dimensional model representing the geometric configuration, component arrangement, and overall working mechanism of the machine.

The resulting engineering design included the machine's main components: the blade plate, cutting system, machine frame, transmission system, as well as safety and maintenance elements. All components were designed with functional, ergonomic, safety, and manufacturability considerations in mind, meeting the needs of medium-sized industries.

The results of the redesign of the Mucuna slicing machine developed based on the design parameters are shown in Fig. 3, which shows the overall appearance of the machine and the configuration of the main components as a basis for subsequent detailed design and performance testing.

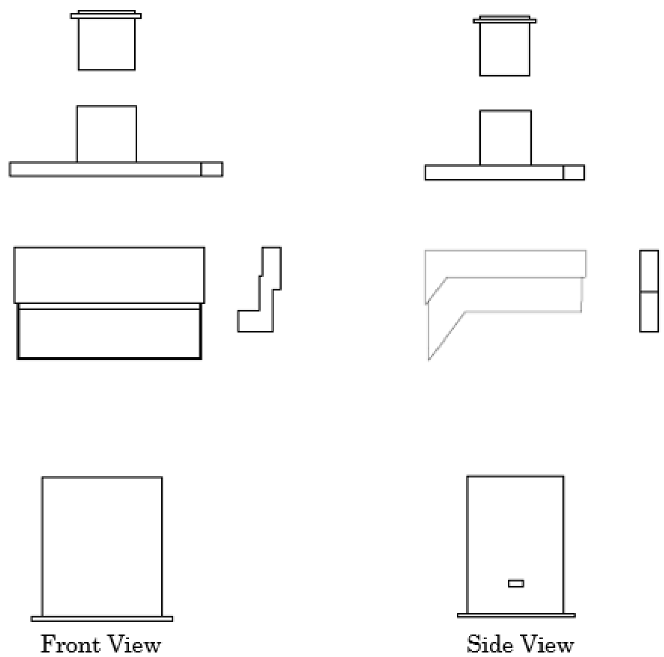

Figure 3. Mucuna slicing machine redesign. (a) Design from front view (b) Design from side view.

5. Conclusion

Based on the results of the Axiomatic Design (AD) analysis in the redesign of the Mucuna slicing machine, several key points can be concluded: a. Design Optimality (Axiomatic Design): The resulting product design matrix exhibits a diagonal structure, confirming that the proposed design meets the Axiom of Independence. This indicates that each functional requirement can be adjusted independently, resulting in a robust and minimally complex design. b. Design Performance Improvement: the design results that the proposed design has two blades with a thickness of 2 mm, a 1/4 Hp dynamo, which requires an adjustment to the target capacity of ±10 kg/hour, dimensions of machine was 300 mm in length, 250 mm in width, and 399 mm in height.

The implications of this research indicate that Axiomatic Design can be effectively applied as a framework for redesigning medium-scale industrial food processing machines, particularly for Mucuna, a relatively hard commodity that demands cutting precision. This approach is able to integrate user requirements into a systematic and measurable design structure. Practically, the design structure resulting from this research has the potential to increase productivity, slice thickness uniformity, occupational safety, and ease of maintenance of the Mucuna slicing machine. The decoupled design also provides flexibility for medium-sized industrial players to adjust or develop specific components without requiring comprehensive changes to the machine system. Therefore, the results of this research can serve as a reference for the development of more efficient, safe, and sustainable Mucuna slicing machines for MSMEs and medium-sized industries.

Further research is recommended to develop this design to the detailed design and prototyping stage, followed by experimental testing to quantitatively validate the machine's performance, particularly regarding production capacity, slice thickness uniformity, energy consumption, and vibration levels. Furthermore, it should also quantitatively integrate ergonomics aspects, and consider Green Design or Life Cycle Assessment (LCA) approaches to comprehensively evaluate the machine's environmental impact.

Author Contributions: Conceptualization: Author 1; Methodology: Author 1; Software: Author 2; Validation: Author 3; Formal analysis: Author 4; Investigation: Author 5; Resources: Author 6.; Data curation: Author 5; Writing—original draft preparation and Writing—review and editing: Author 6; Visualization: Author 3; Supervision: Author 1; Project administration: Author 1.

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