

## DEVELOPMENT OF A LOW-COST HOT AIR COFFEE ROASTER FOR HOME APPLICATION

M. N. I. Mohd Nasir<sup>1</sup>, N. Abdul Rahman<sup>1</sup>, P. Z. N. Megat Zamanhuri<sup>2</sup>, M. Katon<sup>1,\*</sup>

<sup>1</sup>School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Cawangan Terengganu, Kampus Bukit Besi, 23200 Bukit Besi, Dungun, Terengganu.

<sup>2</sup>Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology,

matzainikaton@uitm.edu.my

### ABSTRACT

This paper presents the development of a cost-effective hot air coffee roaster tailored for home use, achieving a significant price reduction of approximately 50% compared to similar products in the Malaysian market. The design process, which includes conceptual design, embodiment design, detailed design, prototyping, and testing, was centered around cost-efficiency. As a result, a functional hot-air coffee roaster was developed at an affordable price for home coffee enthusiasts, enabling them to customize their coffee roasting process and achieve their preferred flavor profile at home.

**Keywords:** Hot Air Coffee Roaster, Mechanical Engineering Design

### 1.0 INTRODUCTION

Coffee roasting has traditionally been achieved using methods that employ a clay or steel pan over an open fire or other heat source [1]. While these methods offer a degree of simplicity, they are limited by inconsistencies in heat distribution, which can negatively impact the final flavor profile of the roasted coffee beans [2]. Additionally, traditional roasting methods often lack precise control over the process, making it challenging to achieve consistent results and replicate desired roast profiles.

Hot air roasters represent an alternative solution to traditional roasting methods. This method utilizes forced convection, the movement of hot air, to efficiently transfer heat to the coffee beans [3]. This approach allows for precise temperature control throughout the roasting process, leading to consistent results and enabling the development of high-quality roasts with well-balanced flavor profiles [4]. Compared to traditional methods, hot air roasters offer greater control over roast time, temperature, and airflow, facilitating increased customization and experimentation with roast profiles.

Despite the numerous advantages of hot air roasters, their widespread application, particularly for home use, faces a significant barrier, which is cost. Commercially available hot-air coffee roasters are often expensive, limiting accessibility for many home coffee enthusiasts [5]. This high cost can be attributed to factors such as the use of expensive materials and the utilization of inefficient manufacturing processes. Consequently, a large coffee enthusiast market is excluded from experiencing the benefits of this superior roasting technology.

This paper explores the development of a low-cost hot-air coffee roaster specifically designed for home application. The research focuses on identifying and implementing cost-effective solutions throughout the engineering process. Through the optimization of material selection, manufacturing techniques, and design complexity, the aim is to create a hot-air coffee roaster that is affordable and accessible to home brewers. This will ultimately empower them to explore the nuances of coffee roasting, experiment with various roast profiles, and craft their perfect cup of coffee at home.

## 2.0 METHODOLOGY

Figure 1 below shows the flowchart of developing a hot-air coffee roaster for home applications.

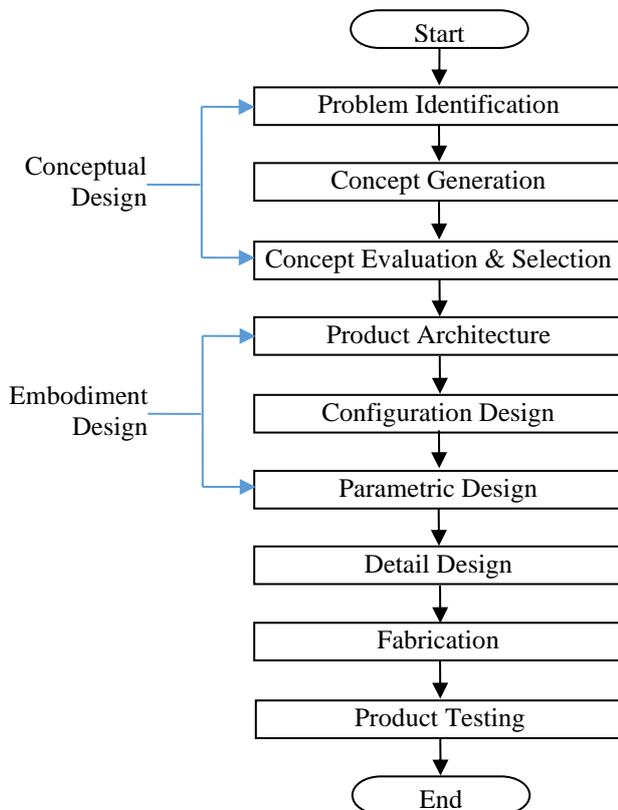


Figure 1: Flowchart of of Development of Hot Air Coffee Roaster for Home Application

In this study, the focus of the design is to introduce a low-cost hot-air coffee roaster to the home market segment. However, the customer requirement (CR) of this product must be identified first. The interviews were conducted physically and online with people who had experience roasting coffee beans. This is to get feedback and information about what must be done to develop the hot-air coffee bean roaster. As a result, Table 1 shows the CR for developing hot-air coffee bean roasters for home applications. Eight CRs were identified: Safety, Capacity, Roasting Performance, Heating System, Airflow Control, Cooling Mechanism, Durability and Low Cost. Table 2 shows the engineering characteristics (EC) for developing hot-air coffee bean roasters for home applications. Seven ECs were identified: Heating Element, Weight, Cost of Production, Power Supply, Dimensions, Temperature Control, and Types of Blower Fan. These CRs and ECs will then be applied to develop the House of Quality (HOQ) diagram.

The HOQ serves as a proven framework for product development centered around human needs, utilizing both customer attributes and product requirements as integral components in defining a product and its key characteristics [6]. Table 3 shows the HOQ of developing a hot-air coffee bean roaster for home application. Based on the HOQ table, the customer gives the highest weightage, resulting in 16.67% of the total, to the safety and low-cost factors, compared to others. Regarding engineering characteristics, the cost of production is valued at 20.23%. Therefore, the Product Design Specification (PDS) table emphasizes the following factors: safety and low cost of production.

A Product Design Specification (PDS) is an exhaustive document that outlines all aspects of a product’s design, functionality, and performance, acting as a standard and guide for all stakeholders in the product development process [7]. Table 4 shows the PDS of developing a low-cost hot-air coffee bean roaster for home application. Nine parameters have been considered in the PDS. These specifications are later used as the guidelines for generating and selecting the final concepts of hot-air coffee roasters.

Table 1: Identified Customer Requirements (CR) of Hot Air Coffee Roaster for Home Application

<b>Customer Requirements (CR)</b>	<b>Description</b>
Safety	The roaster should prioritize user safety by minimizing hazards like burns, fire risks, and electrical malfunctions.
Capacity	The roaster should be able to accommodate a sufficient amount of coffee beans for a single roast, catering to the typical needs of home users.
Roasting Performance	The roaster should deliver consistent and high-quality roasts, allowing users to achieve their desired roast level (light, medium, dark) with good control over temperature and roast time.
Heating System	The heating system should be efficient and cost-effective, ensuring even heat distribution throughout the roasting chamber to avoid unevenly roasted beans.
Airflow Control	The roaster should provide a mechanism for users to control airflow during the roasting process. This allows for adjustments based on the desired roast profile and optimizes heat transfer within the chamber.
Cooling Mechanism	The roaster should incorporate a cooling mechanism to quickly bring the roasted beans to a safe temperature after roasting. This prevents over-roasting and preserves the flavor profile.
Durability	The roaster should be constructed with durable materials and components to ensure longevity and withstand regular use in a home environment.
Low Cost	The overall design and manufacturing process should prioritize cost-effectiveness. This includes selecting affordable materials, optimizing production methods, and minimizing unnecessary features to achieve a price point accessible to home coffee enthusiasts.

Table 2: Identified Engineering Characteristics (EC) of Hot Air Coffee Roaster for Home Application

<b>Engineering Characteristics (EC)</b>	<b>Description</b>
Heating Element	This refers to the component responsible for generating heat within the roaster. Factors to consider include: (i) Type: Radiant (e.g., infrared heating elements) or convective (e.g., heating coils) heating can be chosen based on efficiency, cost, and desired heat transfer properties. (ii) Wattage: This determines the heating power and should be sufficient to achieve desired roasting temperatures within a reasonable timeframe.
Weight	The overall weight of the roaster impacts factors like portability, countertop space requirements, and user convenience.
Cost of Production	This encompasses the total cost associated with manufacturing the roaster. Considerations include: (i) Material selection: Choosing cost-effective materials without compromising safety, durability, or roasting performance. (ii) Manufacturing processes: Exploring efficient and cost-saving manufacturing techniques.
Power Supply	This refers to the electrical input required to operate the roaster.
Dimensions	The roaster size should be compact enough for comfortable home use without compromising roasting capacity. Factors to consider include: (i) Chamber size: This should accommodate the desired roasting capacity while allowing for proper airflow and heat distribution. (ii) Overall footprint: The roaster should fit comfortably on a countertop or designated space without being overly bulky.

**Temperature Control** This refers to the mechanism for regulating the roasting temperature within the chamber. A reliable and accurate temperature control system is essential for achieving consistent roasts. (i) Sensor: A temperature sensor accurately monitors the roasting chamber's temperature. (ii) Control Panel: Users should be able to easily set and adjust the desired roasting temperature through an intuitive interface.

**Types of Blower Fans** The blower fan type influences airflow within the roasting chamber, impacting heat distribution and roast quality. Factors to consider include: (i) Fan size and power: This should ensure adequate air circulation throughout the beans. (ii) Airflow control: The ability to adjust the airflow allows users to tailor it to different roast profiles.

Table 3: House of Quality of Hot Air Coffee Roaster for Home Application

Relative Important (%)	Customer Importance	Customer Requirements	Functional Requirements					Product A	Product B	Product C		
			Heating Element	Weight	Cost of Production	Power Supply	Dimensions				Temperature Control	Types of Blower Fans
16.67	5	Safety	9		3	3		9	1	1	5	5
10.00	3	Capacity		9	9	9	3	1	1	5	3	3
10.00	3	Roasting Performance	3	1	3			1		3	5	5
13.33	4	Heating System	9	1	3	3		3		3	5	5
13.33	4	Airflow Control		3	3	3			9	3	3	5
10.00	3	Cooling Mechanism	1	1	1					3	3	3
10.00	3	Durability	1			3			3	3	3	5
16.67	5	Low Cost	3	9	9	9	3	1	3	5	3	3
<b>Importance Rating Sum</b>			<b>370</b>	<b>313</b>	<b>410</b>	<b>400</b>	<b>80</b>	<b>227</b>	<b>227</b>			
<b>Relative Weight (%)</b>			<b>18.25</b>	<b>15.46</b>	<b>20.23</b>	<b>19.73</b>	<b>3.95</b>	<b>11.18</b>	<b>11.18</b>			

Table 4: Product Design Specification of Low-Cost Hot Air Coffee Roaster for Home Application

No.	Parameter	Specification
1	Performance	This coffee bean roaster can determine the desired level of roasting, for example, light, medium, and dark levels of coffee beans with consistent and even heat distribution. It can also precisely control the temperature to achieve optimal roasting results. The roasting time can be adjusted to accommodate different types of coffee beans and the desired roast profile.
2	Capacity	This coffee bean roaster will determine the maximum and minimum rate of coffee beans that can be roasted in a time so that the coffee beans can be produced perfectly and according to the customer's taste.
3	Circulation	This product will ensure that the hot air circulation system for my products is in good condition and efficient to ensure even roasting and flavor development.
4	Safety	This product would prioritize overheating protection by adding an automatic shut-off feature to prevent accidents with the product, coffee beans, and users. The heat-resistant exterior will also be prioritized to prevent burns and ensure user safety.

5	Construction	This product will use durable stainless steel for durability and heat resistance. It will also be designed with a compact and lightweight design for easy storage and portability.
6	Cleaning	This product will make sure the parts of this coffee bean roaster are easily removable for easy cleaning and maintenance.
7	Dimension	This product will make sure the dimensions of my product are suitable for an unseated home.
8	Cost	This product will minimize the expenditure cost for the coffee lover can effort it.
9	Target market	The target market for this product is coffee lovers of all ages, and it is affordable for all levels. My product needs to be consistent and creative to fit my target market. This product will make it original and bold to attract the attention of coffee lovers.

### 3.0 RESULT AND DISCUSSION

Physical decomposition, the process of splitting a product or subassembly into its individual parts and smaller assemblies while describing their functional relationships, is a critical step toward comprehending product functionality [8]. This approach can be demonstrably applied to hot-air coffee roasters. A hot air coffee roaster can be broken down through physical decomposition into its main components, including the heating element, roasting chamber, blower fan, control panel, and chaff collector (Figure 2). This breakdown then lays the foundation for functional decomposition, which focuses on identifying each component's specific functions within the roaster.

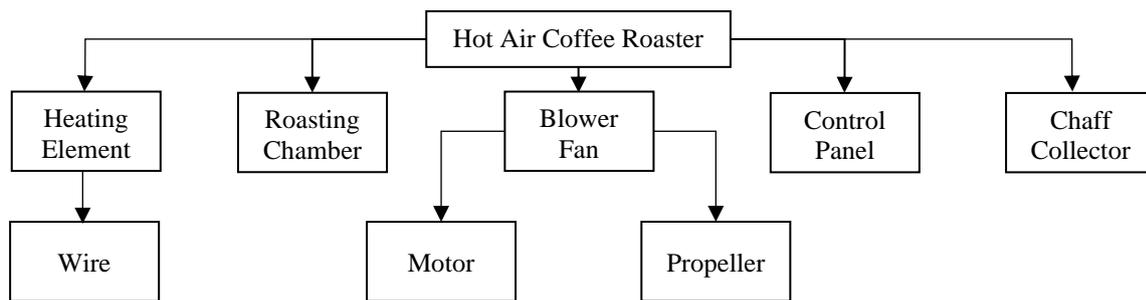


Figure 2: Physical Decomposition of Hot Air Coffee Roaster for Home Application

The function structure shown in Figure 3 is a graphical illustration of a functional model. It shows the function as an entire system comprising interconnected sub-functions that operate on specific flows [8]. The three types of flow, material flow, signal flow, and energy flow, are easily understood.

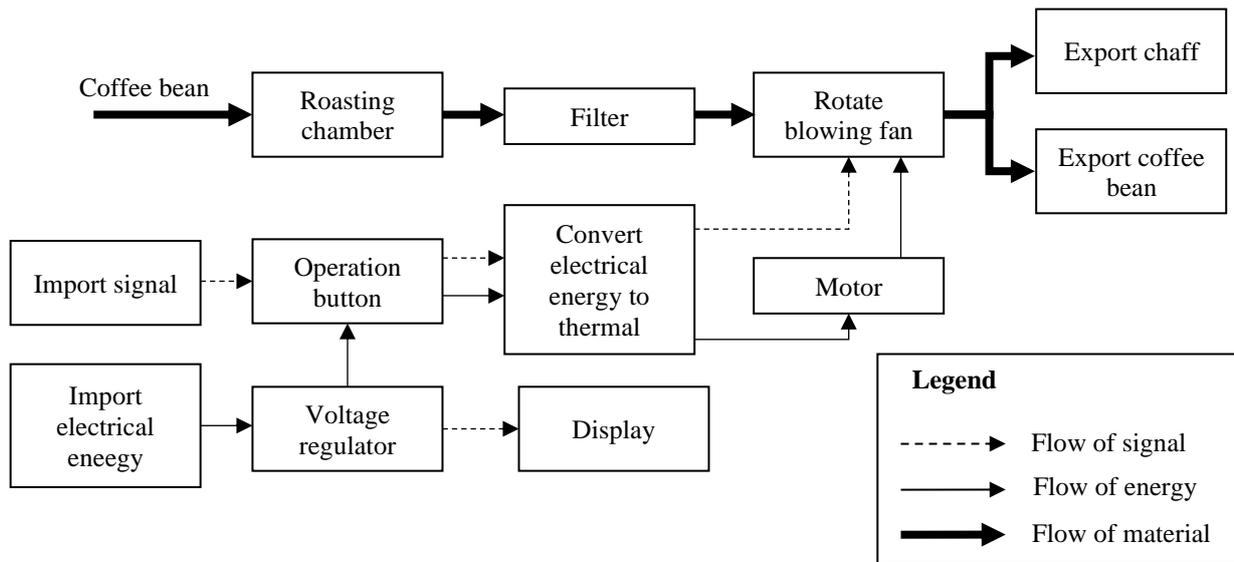


Figure 3: Function Structure of Hot Air Coffee Roaster for Home Application

The systematic study of potential forms and shapes is conducted through morphological analysis [9]. Table 5 shows the morphological table for the hot-air coffee roaster. The table, characterized by its list of identified device sub-functions on the left side, presents potential solution options for each sub-function on the right. With seven sub-functions, each having a five solution options, five concepts are subsequently derived. These concepts are formed through the potential combinations of solution options for each sub-function. The possible combinations of option solutions for each sub-function are described as in table 6.

A weighted decision matrix is a commonly used design technique for evaluating alternative concepts. It assigns scores to each concept based on how well it aligns with the design criteria, considering the weighting factors associated with those criteria [10]. The Weighted Decision Matrix is applied to five concepts from Table 6. The outcomes are displayed in Table 7. Table 7 shows net scores for Concepts 1 to 5 as 10, 16, 0, 4 and 10 respectively.

Table 5: Morphological Table for Hot Air Coffee Roaster

Sub-function	Option-solution 1	Option-solution 2	Option-solution 3	Option-solution 4	Option-solution 5
Roasting chamber	A1  Top cover	A2  Front cover	A3  Top twist	A4  Chamber twist	A5  Side cover
Power Source	B1  3-pin plug	B2  2-pin plug	B3  USB	B4  Battery 9-Volt	B5  Battery 2A
Chaff collector	C1  Filter basket	C2  Flat filter	C3  Side filter	C4  Top filter	C5  Half filter

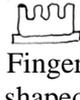
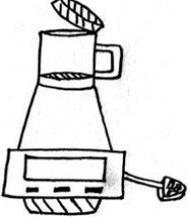
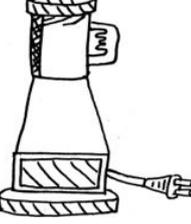
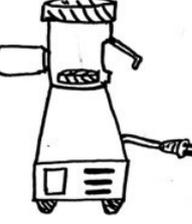
Joint	D1	 Rivet	D2	 Nail	D3	 Screw	D4	 Hot glue gun	D5	 Welding
Control system	E1	 Digital	E2	 Analog	E3	 Function	E4	 Touch screen	E5	 Option
Handle	F1	 U-shaped	F2	 Straight	F3	 Finger shaped	F4	 Top	F5	 L shaped
Base	G1	 Round	G2	 Rectangle	G3	 Rubber	G4	 Locked roller	G5	 Wood

Table 6: The Combinations of Option-Solutions for each Sub-Function

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Sketches					
Description	Precise and easy operation, clean roasting experience.	Precise and intuitive adjustments for desired roast profiles, stable and durable.	Easy access for loading/unloading, precise and intuitive adjustments for desired roast profiles, efficient chaff removal, comfortable grip for manoeuvring.	Convenient and efficient operation, effective chaff removal, easy function selection for precise control, stable operation.	Roasting nuts and coffee beans, user-friendly operation with multiple settings.
Option-Solution	A1, B1, C2, D1, E1, F1, G1	A1, B1, C1, D3, E2, F1, G2, G3	A3, B2, C3, D1, E4, F3, G3	A3, B3, C1, D2, E3, F3, G4	A5, B2, C1, D3, E5, F5, G2

With a score of 16, Concept 2 outperforms the other concept. It excels in safety, affordability, roasting efficiency, and aesthetics, making it the top choice for the final concept. This concept, aimed at developing a hot air coffee bean roaster for home use, shows promise in enhancing the home coffee roasting experience while being cost-effective and safe. Its superior performance in key areas establishes it as the preferred choice.

Table 7: Weighted Decision Matrix of Hot Air Coffee Roaster

Parameter	Weightage	Datum	Concept				
			1	2	3	4	5
Safety	5	0	+	+	0	0	+
Capacity	1	0	0	0	-	-	0
Power supply	3	0	0	0	-	0	-
Low cost	5	0	+	+	+	+	+
Roasting	5	0	0	+	0	0	0
Performance	1	0	0	+	-	0	0
Appearance	3	0	0	0	0	0	+
Reliable							
	+		10	16	5	5	13
	-		0	0	5	1	3
<b>Net Score</b>			<b>10</b>	<b>16</b>	<b>0</b>	<b>4</b>	<b>10</b>

Next, embodiment design is done on the design process which involve product architecture, configuration design and parametric design. Product Architecture is the process of organizing a product's functional elements, linking them to physical components, and defining how these components interact [11]. Configuration design is a phase where the designer provides definition, dimension, or shape to each component or function of a product, which strongly depends on the selection of materials and its manufacturing techniques [12]. Parametric design is a process where the designer manipulates and optimizes the parameters of a design model, such as material properties, fabrication methods, and shape attributes, to achieve desired performance and aesthetic outcomes [13].

Figure 4 and Figure 5 shows the schematic diagram of the product architecture and the rough geometry layout of the coffee roaster. In the design of the hot air coffee roaster, the control panel is strategically positioned at the front for enhanced visibility and ease of option selection. The motor and blower fan, essential for initiating the roasting process, are located at the bottom to facilitate the movement of coffee beans within the chamber. A filter container is incorporated at the bottom of the chamber to collect coffee chaff. The power supply connection is situated at the rear of the roaster. Table 8 show the list of part that need to buy or fabricate. Table 9 shows the part that need to fabricate in house with its identified material, manufacturing process and its final shape.

Figure 6 shows the assembly drawings of the hot air coffee roaster. The final design is consist of ten parts, which are; body, control panel, function, chamber, bottom cover, switch, base, upper cover, filter and handle. Figure 7 shows the successfully constructed of low cost hot air coffee bean roaster for home application prototype. Table 10 shows the bill of materials and costing of the hot air coffee roaster. It was found that, the total cost of the prototype is at only RM 226.57. This value is half of the price of the same product available in the Malaysia market. An evaluation of a hot air coffee roaster's performance is shown in table 11. The assessment focuses on achieving roasting accuracy and efficiency through careful monitoring of temperature control, roasting time, and the final color of the roasted coffee beans.

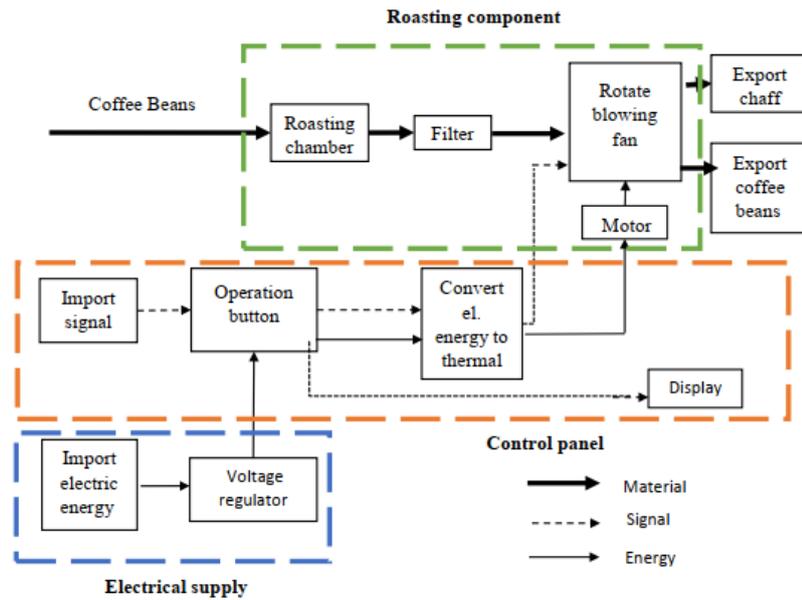


Figure 4: Schematic Diagram of the Product Architecture of the Hot Air Coffee Roaster

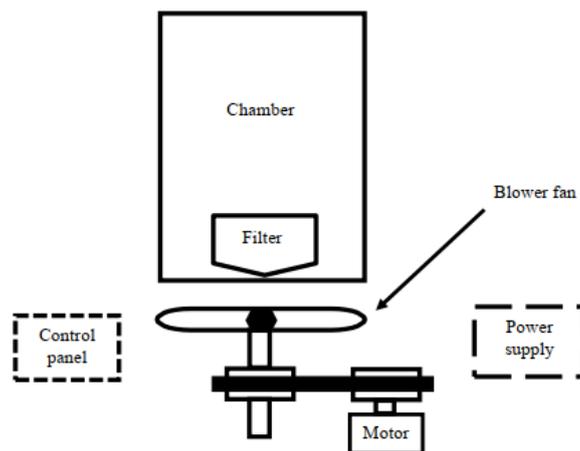


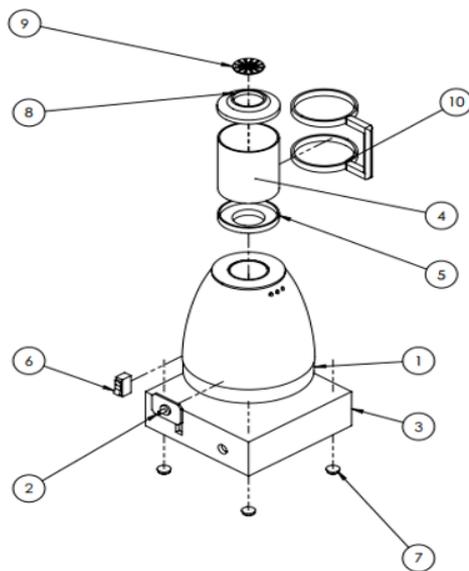
Figure 5: Rough Geometry Layout of the Hot Air Coffee Roaster

Table 8: Identification of Buy Make Hot Air Coffee Roaster

Component	Motor	Chamber	Nichrome wire	Blower fan	Control panel	Frame	Filter	Plug
Buy/Make	Buy	Fabricate	Buy	Buy	Buy	Fabricate	Fabricate	Buy

Table 9: Part to Fabricate in House with its Identified Material, Manufacturing Process and its Final Shape.

Part Name	Chamber	Frame	Filter
Function	To place the coffee beans	Housing of the heating and fan elements	To collect the chaff
Material	Stainless steel	Stainless steel	Stainless steel
Manufacturing Process	Drill / Screw joints	Bending / Drill /Screw joints	Drill / Screw joints
Shape			



Item No	Part
1	Body
2	Control Panel
3	Function
4	Chamber
5	Bottom cover
6	Switch
7	Base
8	Upper cover
9	Filter
10	Handle

Figure 6: Assembly Drawing of Hot Air Coffee Roaster



Figure 7: Prototype of Hot Air Coffee Roaster for Home Application

Table 10: Bill of Material and Costing of Prototyping Hot Air Coffee Roaster for Home Application

No	1	2	3	4	5
Item	Temperature Gauge	Hair Dryer	Heat Gun	Wire	Stainless Steel
Quantity	1	1	1	1	2
Figure					
Price per unit (RM)	6.44	15.50	42.63	2.00	80.00
Total price (RM)	6.44	15.50	42.63	2.00	160.00
Total (RM)			<b>226.57</b>		

Table 11: Performance Testing of Hot Air Coffee Roaster for Home Application

Temperature (°C)	Time (Minutes)	Coffee Bean Colour
200	10	Light
220	14	Medium
240	20	Dark

#### 4.0 CONCLUSION

In conclusion, this study has successfully developed the low-cost hot air coffee bean roaster for home use. The customer requirements, collected from the collected data, were involved in identifying the engineering characteristics that were subsequently incorporated into the House of Quality (HOQ) diagram. As a result, a product design specification (PDS) for the coffee bean roaster was developed based on the HOQ, serving as a guideline for concept generation and selection. The weighted decision matrix is used to generate and select the final concepts. It was found that concept 2 is selected for the final concept of the coffee bean roaster, excelling in safety, affordability, roasting efficiency, and aesthetics. The embodiment design has been carried out and is followed by the detail design and prototyping. A simple prototyping test has also been conducted, indicating that the prototype is capable of roasting coffee beans within a specific range of bean roast.

As for the future work, improving on the roasting process based on user feedback and investigating the integration of smart technologies for enhanced user experience can be done. This could potentially lead to a more personalized and efficient coffee roasting experience at home.

## REFERENCE

- [1] I. K. Suherman, I. W. Suirya, and I. M. A. Adiaksa, "REDESIGN OF HORIZONTAL COFFEE ROASTERS WITH TEMPERATURE, TIME AND ROTATION CONTROLS," *Logic: Jurnal Rancang Bangun dan Teknologi*, vol. 22, no. 2, pp. 184–188, Jul. 2022, doi: 10.31940/logic.v22i2.184-188. [Online]. Available: <http://dx.doi.org/10.31940/logic.v22i2.184-188>
- [2] A. Farah, *Coffee*. Royal Society of Chemistry, 2019 [Online]. Available: [http://books.google.ie/books?id=K7arDwAAQBAJ&printsec=frontcover&dq=10.1039/9781782622437-00726&hl=&cd=1&source=gbs\\_api](http://books.google.ie/books?id=K7arDwAAQBAJ&printsec=frontcover&dq=10.1039/9781782622437-00726&hl=&cd=1&source=gbs_api)
- [3] S. Susilawati et al., "The Analysis of Heat Transfer on Hot Air Coffee Roasters at the Appropriate Technology Research Centre, National Research and Innovation Agency in Subang," *VANOS Journal of Mechanical Engineering Education*, vol. 8, no. 2, p. 121, Nov. 2023, doi: 10.30870/vanos.v8i2.22210. [Online]. Available: <http://dx.doi.org/10.30870/vanos.v8i2.22210>
- [4] M. Gancarz et al., "Impact of Coffee Bean Roasting on the Content of Pyridines Determined by Analysis of Volatile Organic Compounds," *Molecules*, vol. 27, no. 5, p. 1559, Feb. 2022, doi: 10.3390/molecules27051559. [Online]. Available: <http://dx.doi.org/10.3390/molecules27051559>
- [5] D. D. Hidayat, A. Sudaryanto, Y. R. Kurniawan, A. Indriati, and D. Sagita, "DEVELOPMENT AND EVALUATION OF DRUM COFFEE ROASTING MACHINE FOR SMALL-SCALE ENTERPRISES," *INMATEH Agricultural Engineering*, vol. 60, no. 1, pp. 79–88, Apr. 2020, doi: 10.35633/inmateh-60-09. [Online]. Available: <http://dx.doi.org/10.35633/inmateh-60-09>
- [6] L. Augustin, A. Wolfram, C. Beyer, B. Kokoschko, and P. Frilling, "Improving Customer Attribute Management Within the House of Quality by Integrating the Non-User," Volume 6: 33rd International Conference on Design Theory and Methodology (DTM), Aug. 2021, doi: 10.1115/detc2021-66868. [Online]. Available: <http://dx.doi.org/10.1115/detc2021-66868>
- [7] H. Hu, Y. Liu, X. Guo, and C. Fu, "A Conceptual Design Specification Based on User Aesthetic Information Analysis and Product Functional Reasoning," *Machines*, vol. 10, no. 10, p. 868, Sep. 2022, doi: 10.3390/machines10100868. [Online]. Available: <http://dx.doi.org/10.3390/machines10100868>
- [8] D. Göhlich, B. Bender, T.-A. Fay, and K. Gericke, "PRODUCT REQUIREMENTS SPECIFICATION PROCESS IN PRODUCT DEVELOPMENT," *Proceedings of the Design Society*, vol. 1, pp. 2459–2470, Jul. 2021, doi: 10.1017/pds.2021.507. [Online]. Available: <http://dx.doi.org/10.1017/pds.2021.507>
- [9] B. Andreas, P. Marina, R. Dmitry, and T. Vladislav, "Automation of the conceptual design in engineering project management based on morphological approach," *Reports in Mechanical Engineering*, vol. 3, no. 2, pp. 225–234, Dec. 2022, doi: 10.31181/rme20009022022a. [Online]. Available: <http://dx.doi.org/10.31181/rme20009022022a>
- [10] L. Gebrehiwot et al., "Rocket launching site selection in Ethiopia using Weight Decision Matrix analysis," *Malaysian Journal of Society and Space*, vol. 19, no. 1, Feb. 2023, doi: 10.17576/geo-2023-1901-01. [Online]. Available: <http://dx.doi.org/10.17576/geo-2023-1901-01>
- [11] D. Bhasin, D. Staack, and D. A. McAdams, "Designing Robust Systems Using Bioinspired Product Architecture," Volume 6: 33rd International Conference on Design Theory and Methodology (DTM), Aug. 2021, doi: 10.1115/detc2021-68956. [Online]. Available: <http://dx.doi.org/10.1115/detc2021-68956>
- [12] V. Karandikar, S. Bade, and S. Patil, "Design for manufacturing and Assembly practices in early stage of product development," *International Journal of Current Engineering and Technology*, vol. 11, no. 05, pp. 509–515, Oct. 2021, doi: 10.14741/ijcet/v.11.5.3. [Online]. Available: <http://dx.doi.org/10.14741/ijcet/v.11.5.3>
- [13] V. Kondyli, M. Bhatt, and E. Spyridonos, "Visuo-Locomotive Complexity as a Component of Parametric Design for Architecture," *Design for Tomorrow—Volume 2*, pp. 993–1004, 2021, doi: 10.1007/978-981-16-0119-4\_80. [Online]. Available: [http://dx.doi.org/10.1007/978-981-16-0119-4\\_80](http://dx.doi.org/10.1007/978-981-16-0119-4_80)