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CONCEPTUAL DESIGN USING EVAPORATING CLOUD METHOD

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Abstract: This study investigates the conceptual design of a cucumber grating tool tailored for small-scale industries in Aceh, Indonesia, utilising additive manufacturing (AM). Driven by the local demand for efficient, cost-effective production tools in the food sector, the research presents a prototype created via 3D printing technology. Utilising the Evaporating Cloud method and semantic design principles, the study emphasises a function-driven approach in the context of home-industry manufacturing constraints. The prototype consists of eight components made from PLA, produced with varying infill densities (50%–100%) and patterns (grid, cubic, octet), focused on optimising strength, functionality, and material efficiency. The printing process lasted 8 days, 14 hours, and 29 minutes, consuming approximately 2987 grams of filament. This involved crafting designs and CAD models that clarified the assembly process, emphasising gear mechanism functionality and the material processing flow. The findings highlight the viability of using AM for tool production in low-resource environments and indicate future improvements through lean design practices and sustainable material usage. This research lays the groundwork for scalable and innovative product development in local industries using AM in alignment with Industry 4.0 objectives.

Keywords: conceptual design, design for manufacturing, additive manufacturing; 3D printing, evaporating cloud.

1. INTRODUCTION

Industrial development based on data from the Indonesia Government Central Statistics Agency (BPS), it was recorded that until 2020, there were around 6,000 small and medium enterprises (SMEs) in Aceh province [1], [2] The real challenges faced by SMEs are limited funding, low levels of human resources, and low technological equipment proficiency [3-8]. In addition, inadequate management competency, lack of workforce skills, weak marketing strategies, and low efforts in research and development to produce quality products from innovative technology. These are the essential factors that cause the unstable growth of SMEs [9]. For SMEs in Aceh province, the logistics sector is the main problem, as it is geographically located in the westernmost part of Indonesia. The SMEs industrial process in Aceh generally still uses manual labour and traditional technology. When the production capacity cannot meet the demand, the immediate effective solution is to use machines to support the production. However, the machines needed in SME industries are rarely the same; thus, the solution is to design a machine that explicitly fits the SME production characteristics and specifications [10].
In the industrial and manufacturing sector, the design of a specific product or component starts with a concept formulated from the function design purpose or an improvement of the original in the existing product process, output parameters, components selection, materials, and limitation [11-15]. Additive manufacturing (AM) is pioneering product development in Industry 4.0 with mass production process development and manufacturing processes that require reverse engineering. Consequently, AM is classified as a crucial innovation technology in product making because of its ability to create objects with the characteristics of complex shapes of design [16-20]. The use of AM in the industry continues to grow as a new technology that enhances the creativity of design freedom, cost-effectiveness, decentralised production, and intellectual property protection of the in-house output [21-24] AM offers a solution to reduce waste in conventional manufacturing techniques at the design development phase, which starts with conceptual design [20].
Indonesia, as an archipelago country, has plenty of ethnicities and cultures. Furthermore, Aceh province has local cultures affected by the old traditions of ancestors and external factors in its food development [25-28]. One of the local culinary specialities in Aceh is 'Kuah Beulangong', which is a beef or goat stew and jackfruit cooked in a wok with a diameter of around one metre and can serve up to more than 200 portions. This food is

served on special occasions such as Islamic celebration days, wedding receptions, family gatherings, and in restaurants. Commonly, this cuisine in Aceh is paired with a grated cucumber drink. Cucumbers are a natural product that is beneficial to hypertension patients for lowering blood pressure caused by water and potassium content in the cucumber to lower the blood pressure [29-32].

The process of grating cucumber drinks in Aceh primarily uses manual labour since 'kuah beulangong' is to celebrate and improve the social relationships in respective local communities in Aceh. However, when this province's culinary served in a restaurant, there is a slight change, particularly in labour cost and hygiene factors it has made. Until now, there have been no business ideas to make this drink into packaging and sell it with massive production intentions. This research proposal will slightly discuss the process of the cucumber grating machine made, the concept design product framework, and the fabrication challenge in making this machine as a foundation of future research in innovating products with AM system, especially the use of 3D printing whether it stopped at laboratory prototype phase or passed the final phase that can be commercialised distributed to the market.

This paper research investigates the potential of AM as a component used in designing equipment tools for cucumber graters based on the conceptual 3D model in the form of a prototype. Furthermore, the potential results of this study are to define the amount of time needed to print the whole tools components of the cucumber grater machine, the amount of filament required to print, and find the limitations in the making process for design improvement to filling the gap of research in product design and responding to the needs of local industry issues in the manufacturing system of SMEs in Aceh.

2. MATERIALS AND METHODS

2.1. Design rationale

A compelling rationale for engineering design ought to be grounded in comprehensive and pragmatic principles derived from human experience. Although these principles may not be demonstrable through pure logic, designers must maintain internal consistency and integrate with a structured disciplinary framework. This framework provides a sense of security and guidance, ensuring that the design philosophy is not just a set of abstract ideas but a practical tool for effective implementation. Thorough and applicable principles are the foundation of design philosophy because they can transform practical techniques into an effective implementation, allowing for a systematic approach that bridges theoretical concepts with tangible outcomes. Nevertheless, the lack of a straightforward operational process and the essence of design rationale can be compromised, making these principles ineffective in practice. A practical design philosophy must also include a feedback mechanism to evaluate its success with the aim of continuous improvement (Kaizen), whether in design or system, by using specific criteria to minimise subjectivity and context dependence. As illustrated in Fig. 1, an evaluative system helps identify strengths, expose weaknesses, and guide improvements, ensuring the philosophy remains relevant and practical [33-37].

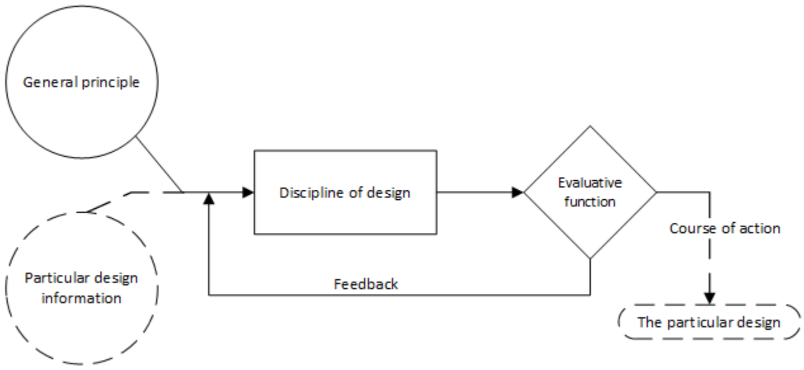


Fig. 1. Design principal flow [33]

This study employs a semantic diagram as the principle of the design rationale in the product development process. As illustrated in Fig. 2, the diagram analyses the designed flow to ensure alignment with the intended design objectives. It highlights three stages of design thinking, as follows: The first stage entails developing a comprehensive systems approach to the specified problem criteria and proposing a preliminary solution based on the design aims, targets, and inherent design limitations. The second stage distinctly frames the problem and solution by emphasising a focused perspective on critical and limiting aspects of the aims, alongside the basis of contradictory gestalt in producing results that correspond to one another to some extent. Furthermore, designers must scrutinise the problem from a detailed standpoint to articulate the issue that triggers the materialisation of pre-restructuring design concepts.

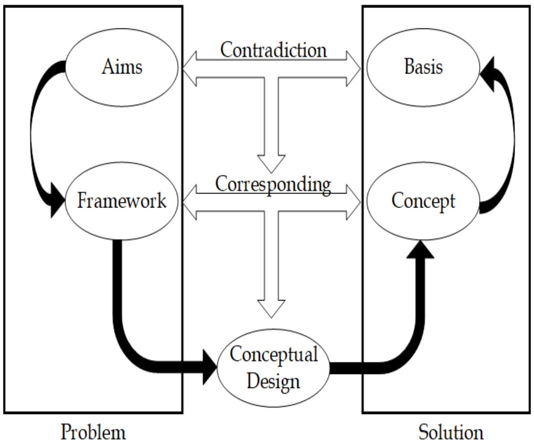


Fig. 2. The study workflow

The final stage involves the emergence of a design based on the second stage, which serves to distinguish and utilise the relevant key knowledge regarding correlation to yield a conceptual design outcome. Moreover, designers, whether explicitly or implicitly, rely on the 'first stages' in concept origination and the comprehensive formation of the concepts.

2.2. Evaporating cloud method

The Evaporating Cloud (EC) diagram is a tool commonly used in project management Theory of Constraints (TOC) methodology to solve bottleneck issues by visualising the contradiction in the system [15], [38]. In design, this tool helps develop a thinking system to identify the priority aims of the design by preventing scope creep in the process of product-making. The EC steps, according to the TOC methods, are as follows five steps:

-The first phase of EC involves discovering the objectives. By streamlining the process flow, this process constrains the fundamental purpose of design thinking. This step is to create a functional and cost-effective grating tool using a mechanism as the fundamental of this study design. Furthermore, the design system is elaborated into simplified diagrams, aiding in manufacturing prototypes.

-The second phase is identifying conflicting needs, which, in this case, is determining the design's goals and needs. This step defines the relative feasibility of the design manufacturing process limitation, which must ensure the designed tool is easy to use and efficient and keeps production at a low cost. Consequently, designers are required to identify the challenges faced in improving the product or system, as shown in Fig 3.

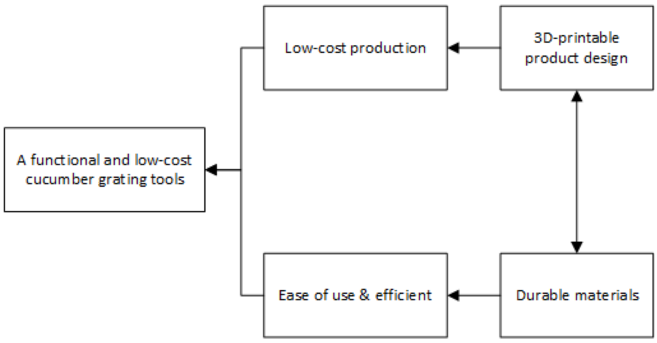


Fig. 3. The fundamental purpose of the grating tool

-The third phase is to specify the problems and objectives. According to Fig. 4, the objective was obtained by mapping the current issues and generating solutions from the problems. The issue with the current cucumber grating process is using a grating hand tool, which increases the risk of a hand injury. Consequently, the idea of grating the cucumber process is to put the grater in something like a rotating plate holder to use the rotation transmitted from the lever mechanism by hand.

-The fourth phase generates a conjecture from the previous step based on the identified assumptions behind the conflict. Additionally, the assumptions in this design, such as design complexity affecting efficiency, 3D design compromising durability and performance, the limitations of the manual mechanisms exerted, and the durability of the filament to withstand the grating process, were considered. As shown in Fig. 5, the purpose was to enhance the final phase and make the solutions more detailed, specifically within the limited constraints of the design parameters.

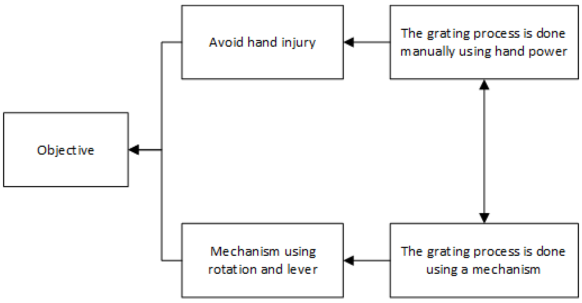


Fig. 4. The process objective of the grating tool

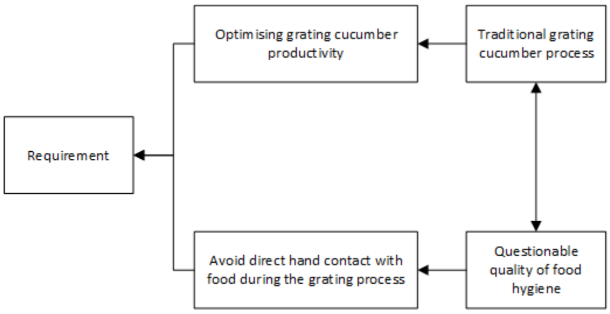


Fig. 5. The requirement of the product

-The last phase articulates the interposing conflict by meeting the objective goals and specification requirements. As shown in Fig. 6, the formulated process flow that started from the objective at phase three and the requirement at phase four output is the sketch idea of the design model and mechanism.

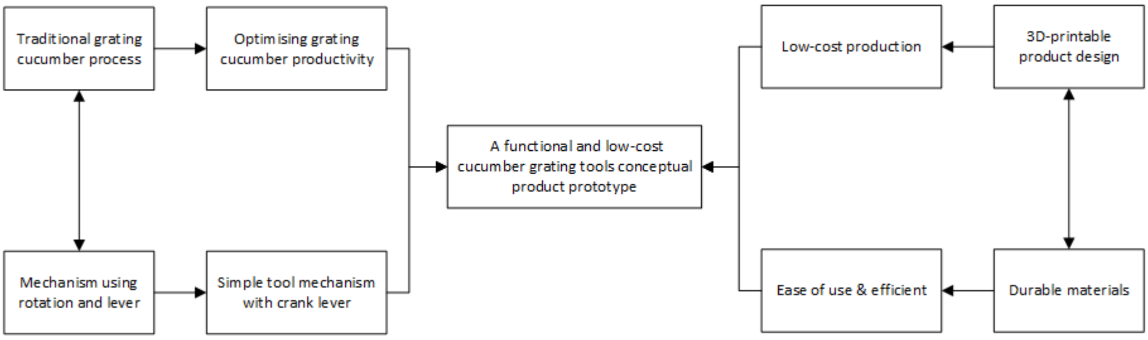


Fig. 6. Design framework EC diagram

The designer's approach and analysis significantly influence the input parameter process of the EC diagram. Crucially, the designers' experience plays a vital role in deriving design constraint parameters, specifying the objectives, and determining the tool alongside the machine requirements. This study emphasises using constraint parameters to maintain a minimalist design by reducing complexity while optimising blade arrangements for enhanced grating performance. This process aims to validate the formulated design hypotheses during the conceptual design phase, identify potential issues, and pursue improvements in the design for the prototyping stage.

The collected parameter is processed by formulating it into a raw sketch design, producing an engineering design using Autodesk Inventor Professional 2025 CAD software. Then, each part is continued to Ultimaker Cura software to determine the component parameter and create the G-Code for the AM process using the Creality Ender-3 3D Printer.

3. RESULTS AND DISCUSSION

3.1. Raw sketch design

The initial step in this study involves visualising the process and the foundation shape as a sketch design. This process is essential to help the designer as it is a vital step in adjusting the shape of the product intended to be manufactured. Based on Fig. 7, the crucial part of the grating or slicing process is the material position flow. This research emphasises the simplicity of the process. Therefore, the cucumber/material input is positioned vertically to erase the complexity of the slicing contact between the grater and the cucumber. In addition, when the material input is placed vertically, the grating area is equal to the diameter of the cucumber. Furthermore, the operator only needs to use an aiding tool to push the little cucumber left since most of the process is assisted by gravity, and its material mass pushes down the material into the grater blade.

Based on the comprehensive analysis presented in Figure 8, the designer conducted an extensive examination of the previous data to visualize and conceptualize the fundamental mechanism of the product. This mechanism is engineered to facilitate a rotational motion, which is integral to its intended functionality. It effectively incorporates miter bevel gears, which are crucial for ensuring a seamless and efficient connection between the various components, specifically the rotary disk and the lever. Consequently, the design not only enhances operational efficiency but also significantly contributes to the overall functionality of the product.

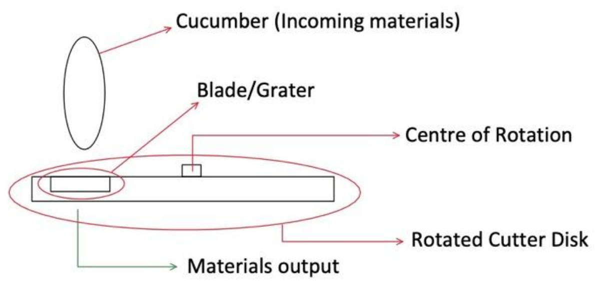


Fig. 7. Raw sketch (a); The slicing or grating flow process sketch (b)

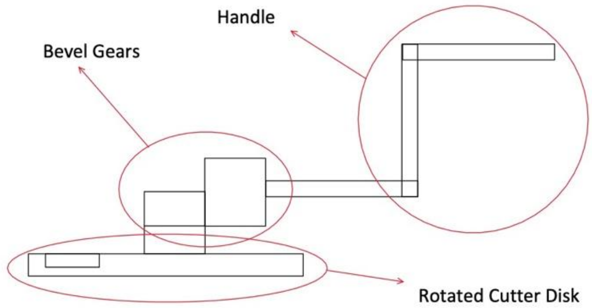


Fig. 8. Raw sketch(a); The working components mechanism concept sketch (b)

As illustrated in both Figures 7 and 8, these illustrations serve a pivotal role in substantiating the rationale behind the product's shape, effectively depicting the interaction among each component within the mechanism. The shapes, sizes, and dimensions of the components designated for the final product are strictly governed by specific constrained parameters, notably those defined by the available 3D printing envelope, measuring 220 x 220 x 250 mm. This limitation ensures that the component design remains feasible for production, while concurrently preserving the integrity and aesthetic appeal of the overall product.

3.2. CAD Design

In the subsequent phase of this study, efforts will be directed towards the enhancement of the design model through the incorporation of more detailed specifications, particularly concerning the dimensions that correspond with the operational area of the 3D printer. This refinement is essential to ensure that each component can be accurately fabricated and efficiently assembled. As demonstrated in Fig. 9, the assembled grating tools have been conceived based on the preliminary sketch design. The design incorporates a semi-circular form that complements the geometry of the rotated disk, while a half-square structure is integrated into the assembly to augment the overall strength and durability of the product. This meticulous attention to design particulars aims at optimizing both functionality and performance in the final assembly of the product.

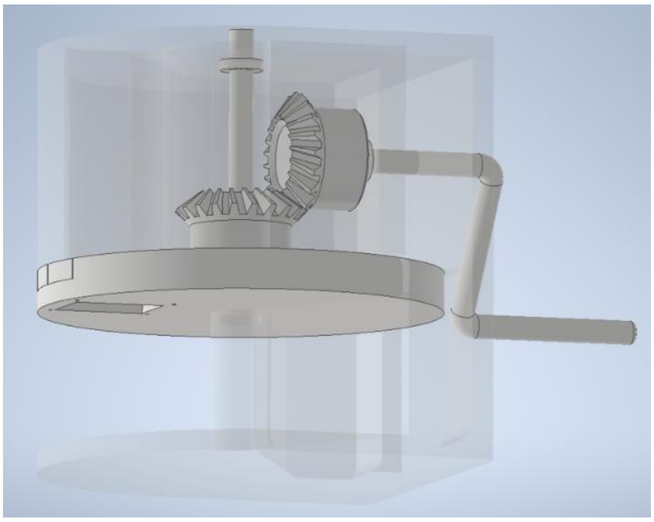


Fig. 9. Grater tool CAD prototype concept

According to the data presented in Table 1, the geometric dimensions of the component are constrained by the available printing area, which is limited to 20 mm within the square dimensions of the printer bed. Furthermore, the maximum height of the product is restricted to 210 mm due to considerations related to the framework of the Z-axis and the wiring connections associated with the nozzle. The length of the lever corresponds to the dimensions of the 3D printer's bed, which measures 220 mm.

Given that the parameters established in this study delineate the maximum print size at 200 mm, the product's configuration is predominantly cylindrical, exhibiting a diameter of 12 mm. This design can be effectively accommodated within the printing area by rotating the object to ensure proper fitting. Additionally, the dimensions of the bevel along both the X-axis and Z-axis measure 64.84 mm, corresponding to the outer circumference of the miter gear components, as clearly depicted in Table 2.

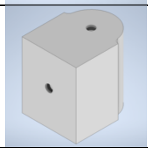
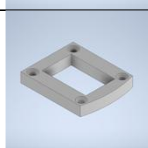
Moreover, the specific selection of bearing used was KNB 6801 ZZ. The grater tool employed in this study necessitates the implementation of metallic components on both sides to maintain direct contact with the bearing during rotation. This design decision underscores the significance of durability and performance in the mechanical interactions inherent to the tool.

Table 1. Grater tools components

Components	Size			
	Length [mm]	Width [mm]	Height [mm]	Diameter [mm]
Body	200	200	210	-
Lever	220	-	102	12
Gear house	108	90	110	-
Bevel X axis	64.84	-	44	50
Bevel Z axis	64.84	-	44	50
Centre shaft	-	-	120	12
Bearing	KNB 6801 ZZ			12
Blade holder	65	54	10	-
Rotary disk	-	-	20	100

The parts designed in this study are illustrated in Table 2, which is eight parts excluding the bearing. Consequently, the concept of the cucumber grating tool component assembly process started by bolting the blade holder to the rotary disk with an M3 countersunk screw while at the same time fitting the bearing KNB 6801 ZZ into the centre part of the body and the gears house. Next, invert the body position and insert the centre shaft through the body, the gear housing, and the bevel Z-axis until it aligns with the central section of the body, where a fitted bearing is attached. Concurrently, insert the lever through the body, the gear housing, and the bevel X-axis until it meets the end of the bearing. This process requires the assembler to perform these actions simultaneously, ensuring that each part fits precisely together without any excessive gaps jammed.

Table 2. Greater tools components

Components	Figure	Components	Figure
Body		Bevel X-axis	
Lever		Bevel Z-axis	
Gears house		Blade holder	
Centre shaft		Rotary disk	

3.3. Additive manufacturing parameters

The last step in this study is to convert the CAD drawing into an STL-type file, which stores the geometry information of the conceptual design. Then, configuring the model inserted parameters, the vital parameter starts from the material chosen, which in this research uses PLA+ considering food grade standard [39]. Before using a 3D printer, the essential parameters to decide are nozzle temperature, plate temperature, layer height, infill, material, speed, support, and build plate adhesion. After determining the parameters, the model must be 'sliced' to create the GCode and determine the estimated printing time and the amount of filament used.
Based on Table 3 shows the fixed parameters input used for the printers. The first concern is the speed print that uses 100mm/s, which is the maximum speed capacity of the printer to speed up the manufacturing process and to discover if any potential issues will arise during the maximum speed process performed. Consequently, because the filament output flow is fast then, it requires the temperature to keep up with the AM process that

will use the 215 ºC at the end nozzle and 60 ºC for the bed as the maximum allowable temperature of PLA+ stated in the filament spool information [40]. Additionally, as the quality of the layer height is 0.2 mm, it defines the typical standard balance between printed product quality resolution and the amount of time needed to print a product.

Table 3. 3D printer fixed settings

Parts	Quality	Material Temperature		Speed
	Layer height (mm)	Nozzle (ºC)	Plate (ºC)	Print Speed (mm/s)
Body	0.2	215	60	100
Lever	0.2	215	60	100
Gears house	0.2	215	60	100
Bevel X axis	0.2	215	60	100
Bevel Z axis	0.2	215	60	100
Main shaft	0.2	215	60	100
Blade holder	0.2	215	60	100
Rotary disk	0.2	215	60	100

The parts in Table 4 show parameter settings for infill, time, and filament. The infill setting refers to the internal structure of the printed parts that provides strength and durability. Also, the infill patterns are the specific geometries that make up this internal structure with the amount of material used. The pattern and infill density choice in this study can be grouped as follows:

1. Grid: This pattern consists of intersecting lines that form a regular grid of squares with moderate strength. This pattern is suited for the lever, gear house, and blade holder parts that require general strength use. The rationale of density used for lever use 100% is that the lever is a transmitting force parts that require infill density to be solid. Moreover, the blade holder only received force in the Z-axis at the 80% infill density and the amount of strength needed with the capacity to hold the M3 countersunk screw-tightened load. Nevertheless, the function of the gears house is utilised as the cover separating the grated cucumber makes direct contact with the bevel miter gears and works as bearing holder support; thus, the 50% infill density is enough for the component's strength.
2. Cubic: This pattern creates a three-dimensional lattice structure that fills the object's interior with high strength. It is suitable to implement where strength is critically required, and weight must be minimised. The rationale of density used for the body with 70% infill is that the body upholds the mass of the whole part, which requires the body to be sturdy. Ideally, it is better to use 100% infill density; however, to save the enormous amount of filament and time consumed, the deciding factor of 70% density is based on the cubic pattern strength capability and pattern layout. Likewise, the main shaft is vital because it is the pivot centre point holding the joined components of the gear housing, bevel gear Z-axis, and rotary disk. Therefore, a 100% infill density must be strong enough to prevent the part from breaking while the tool is used.
3. Octet: This pattern makes a three-dimensional lattice of tetrahedrons arranged in a 3D grid. This produces a rigid internal structure that distributes forces efficiently. The tetrahedral trusses distribute mechanical forces efficiently in all three dimensions. This makes the Octet pattern particularly well-suited for applications where parts must withstand significant stresses or forces applied where maximising, like the bevel gear parts with 100% infill density, ensuring the tool works appropriately to withstand the force at the cutting process while grating cucumber and the torque input from the lever. Correspondingly, the rotary disk infill density is at 80%, with the rationale of density used to withstand the pressure, centrifugal, and centripetal forces affecting the rotary disk during the grating process.

Table 4. 3D printer parts parameter

Parts	Infill	Support	Plate Adhesion	Print Duration		Filament	
	Density (%)	Pattern	Generate/ Type	Type	Time	Mass (gr)	Length (m)
Body	70	Cubic	Yes/Tree	None	5 d 19 hr 53 min	1921	643.89
Lever	100	Grid	No	Brim	3 hr30 min	40	13.30
Gears housing	50	Grid	No	None	20 hr 17 min	251	84.12
Bevel X axis	100	Octet	No	Brim	7 hr 8 min	87	29.29
Bevel Z axis	100	Octet	No	Brim	7 hr 8 min	86	28.93

Main shaft	100	Cubic	No	Brim	2 hr 12 min	17	5.74
Blade holder	80	Grid	No	Brim	2 hr 1 min	23	7.55
Rotary disk	80	Octet	No	Brim	1 d 0 hr 20 min	562	198.48
Total					8d 14hr 29 min	2987	1011.30

4. CONCLUSIONS

Based on the results of this study's process of designing a cucumber grating tool, the conclusion is that the results of a conceptual design generate a prototype product that requires testing, rectifying the prototype flaw, and implementing the Kaizen practice of continuous improvement. The challenging parts of product design are seeking the equilibrium of the product's functionality and deciding the manufacturing process. Therefore, utilising the sketch drawings with the method used to visualise the product design is in accordance. The designer has unrestrained freedom in deciding the dimensions throughout the sketch and product drawings with software. Nevertheless, putting contradictions in place to determine the purpose removes the potential for scope creep in the whole process, simplifying the objective, streamlining the goal of design purpose, and finding the economical manufacturing process without lessening the quality.

The deciding factor in determining the infill parameter is the print time spent with the amount of material filament consumed efficaciously. Though the infill pattern offers similar strength and versatility of function application, the significant element is finding the compatible formulation between the percentage density used appropriately in parallel with its pattern type usefulness. Thus, this study's infill density option is 50%, 70%, 80% and 100% based on the parts function with pattern use grid, cubic, and octet where it requires solidity constrained with the limited number of spool filaments.

Further research is suggested to improve the design, simplify the assembly process based on the lean manufacturing concept, and deeply explore the potential of additive manufacturing in deciding the parameter settings. Furthermore, the waste from the PLA 3D print filament has a high potential for reuse, as its material is based on plastic, which promotes green manufacturing and is environmentally friendly.

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