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CONCEPTUAL DESIGN OF A DOMESTIC POLYMER SHREDDER

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Abstract. *According to recent reports, there is an urgent need for a global agreement to contain plastic pollution that has been advancing in recent years. The lack of recycling results in handling that are not environmentally friendly, such as incineration or outdoors disposal. To help prevent this, the present paper aims to determine the design concept of a domestic machine for shredding polymers. A Product Design Methodology model was adopted, developing the Conceptual Design Phase, which consists of five activities: elaboration of the Functional Structure of the Product; the Morphological Matrix; alternative concepts; Selection Matrix and the selected conceptual design presentation. Essential design problems were defined, the product global function and its sub-functions were elaborated, the solution principles were defined, different solution principles were analyzed, possible combinations of concepts were selected, and finally, an solution was determined using an evaluation matrix. As a result, the polymer shredder Working Structure system breaks down the global function into four Partial Functions and finally divided into sixteen Elementary Functions. Combining the solution principles for each elementary function, three alternative concepts were generated. Those concepts were evaluated in the selection matrix, and it was concluded that concept B best meets this project goals and specifications.*

Keywords: *mechanical design, project methodology, recycling*

1. INTRODUCTION

According to reports published in 2018 by the World Wide Fund for Nature - WWF “What a waste 2.0: A Global Snapshot of Solid Waste Management to 2050” there is an urgent need for a global agreement to contain plastic pollution that has been advancing in recent years. In the global context, the countries that generate the most plastic waste are the United States, China and India. Brazil is in the 4th place, with 11.3 million tons generated per year. Of this total, 10.3 million tons were collected (which represents 91% of total), but only 145 thousand tons (1.28%) are actually recycled. This demonstrates that Brazil has one of the lowest plastic recycling rates, below the world average, which is 9%. Furthermore, Brazil produces an average of 1 kg of plastic waste per inhabitant each week (Kaza et al., 2018).

The portion of plastic waste that is not recycled is destined for incineration. This process releases toxic gases into the atmosphere, which are harmful to human health. In addition, outdoor disposal pollutes aquifers, water bodies and reservoirs, causing long-term increases in respiratory problems, heart diseases and damage to the nervous system of exposed people. For that matter, the ecologically responsible alternative to plastic disposal is recycling, which in addition to reducing the amount of waste, also focuses on less need for virgin plastics usage (WWF, 2019). According to a study by the Federal Government's Institute for Economic and Applied Research (IPEA, 2010), Brazil wastes around R$8 billion a year by taking recyclable materials to dumps and landfills that could return to industrial production. Of this total, R$5.8 billion (72.5%) corresponds only to the potential benefit of recycling plastic materials.

Having demonstrated the environmental and economic importance of recycling, it is understood that it focuses on reducing the impact of materials on the environment throughout their life cycle (EPA, 2020). Taking this into account, it is defined that the type of recycling process used with the desired machine is the mechanical type. Thereby, plastics at the end of their life cycle can be screened, crushed, washed and granulated, and thus, inserted again as raw materials for industry, being transformed again into products. This is the most used way to recycle in Brazil (Fraga, 2014).

The most common process of mechanical recycling has as its main steps the separation of contaminants, milling, washing, additivation, extrusion and granulation of plastic. The separation step can be resumed to removing contaminants from plastic, such as paper, dust or other impurities. During milling, the residues are crushed. Washing, on the other hand, is usually done with water, but caustic soda can be used if chemical washing is necessary. Additivation adds some substance to the product to correct certain properties that are considered deficient. Finally, in the extrusion step, the plastic is extruded into filaments, and then granulated (Fraga, 2014). Although all the steps are essential for plastic recycling, this paper focus on plastic shredding.

The machines that perform plastic milling are called mills or shredders. These machines are characterized in accordance with Standard 15107 (Brazilian Association of Technical Standards, 2017), by cutting plastic materials by shear, through rotating and fixed blades inside the cutting chamber, until their dimensions have been reduced. Besides shear mechanism, what differentiates mills and shredders is their way of driving: while mills are driven by transmission belts, shredders are typically driven by gearboxes (Fraga, 2014).

Based on above, it turns out that there is a low supply in the market for domestic polymer shredders, and commercial products available are aimed at industrial scale applications, as presented by Slaviero et al. (2021). Shredder machines, as well as any industrial product, are developed following a New Product Development Process (NPD). Back et al. (2008) presents a NPD reference model in which it organizes into eight phases that include: Project Planning, Informational Design, Conceptual Design, Embodiment Design, Detailed Design, Production Preparation, Launching and Validation.

For the Informational Design Phase, Slaviero et al. (2021) systematizes customer needs for a domestic polymer shredder, such as: it must be motorized and safe, as a Market Research result. During this phase, four Customer Needs were identified, which were converted into twenty-one Customer Requirements and later translated into nineteen Design Requirements. Seven machines available on the market were identified, the requirements with the highest meeting priority were analyzed using the Quality Function Deployment (QFD) matrix method, and then finishing with the definition of Design Specifications. The following technical specifications are expected to be met: final cost in the range of R$600.00 to R$1,000.00, an engine of at least 1.5 hp (1,103.25 W), being able to reverse its axes rotation and an emergency stop (Slaviero et al., 2021).

In view of the above, this paper aims to present the most suitable product design for a domestic machine to shredder polymers.

2. LITERATURE REVIEW

Recycling materials helps to reduce solid waste disposal in the environment. This process allows the reinsertion of materials in the production process, considerably reducing energy consumption or extraction of raw materials. Plastic material recycling processes can be classified into three types: mechanical, chemical and energetic. In Brazil, the most used technique for tailings recycling is mechanical recycling. This type of recycling reuses industrial waste and post-consumer plastics (e.g., packaging in general) to produce new products (Fraga, 2014).

The material must be collected according to the constituting polymer, as this separation is essential to maintain the quality and properties of the products that will be fabricated from recycled material. The next step is to reduce into small fragments, which helps to process this material in the next stages of recycling. For this purpose, a specifically designed shredder is used to reduce plastic materials into smaller fragments (Mano, 2005).

A polymer shredder has basically four main components, as seen in Figure 1: a feeding unit, a shredder unit, a power transmission unit and the machine structure (Ayo et al., 2017).

Figure 1. Main components of a polymer shredder (adapted from novatechmachines.com).

To develop a product, it is important to use a product design methodology, which aims to demonstrate a planned procedure with conduct indications to observe during the development of technical systems. This documented procedure is a result of knowledge in the design science field and experience in different applications (Back et al., 2008). In regard to that, the applied methodology in this work is Industrial Products Development Process (PRODIP), presented by Back et al. (2008). The process is composed of three macro phases called Planning, Design and Implementation. The Planning macro phase is composed of the Product Planning and Project Planning phases. The Macro Design phase (Romano, 2003) is composed of the Informational Design, Conceptual Design, Embodiment Design and Detailed Design phases. Lastly, the Implementation macro phase is composed of the Production Preparation, Launch and Validation phases. The procedure is done in such a way that each phase generates an output document, which is used as an input document for the next phase.

As the objective of the paper is to determine the most suitable concept for the project, it is verified in the model of Back et al. (2008) that it is necessary to develop the Conceptual Design Phase, which corresponds to the second phase of the Design macro phase. The Conceptual Design Phase is characterized by the creativity employed where alternatives are generated, technically and economically evaluated, and finally, the most representative are selected to solve the problem (Back et al., 2008). According to Pahl & Beitz (2007), Conceptual Design Phase is a part of the design process where the basic solution path is laid down through the elaboration of a solution principle. That is possible by identifying the essential problems through abstraction, establishing function structures, searching for appropriate working principles and combining these into a working structure. Finally, the solution variants that have been elaborated must be evaluated by a methodical application of specific criteria. Based on this evaluation, the best concept can be selected.

3. METHODOLOGY

The methodological procedure adopted is delimited to the elaboration of the Conceptual Design Phase. The objective of this phase is the generation of a conceptual product design. For that reason, four activities were developed in this phase:

1 – The first activity is the development of the Working Structure, which was carried out through a block diagram relating the Overall Function (OF), Partial Functions (PF) and Elementary Functions (EF) of the system. The Overall Function was defined using an oriented abstraction process, suggested by the functional synthesis method. After that, the system's inputs and outputs were defined. Thus, the Overall Function was decomposed into 4 Partial Functions. Finally, the partial functions are broken down into 16 simpler functions, called Elementary Functions.

2 – In the second activity, the Morphological Matrix of alternative solution principles was elaborated. According to Zwicky (1971), this classification scheme is particularly suitable for systematically combining solutions. Existing products in the market were analyzed, along with brainstorming sessions between the designer and his supervisor, so that it was possible to discuss about the solutions, and thus optimize them. The matrix relates each elementary function listed in the previous step with up to 4 solution principles. These principles are exemplified descriptively and symbolically, through sketches for better understanding.

3 – The third activity consists in the development of alternative design concepts. Solution Principles are selected to meet the design specifications defined by Slaviero et al. (2021) to form a set, originating a product concept design. Three alternative designs were determined. Design A aims to be the most economically accessible. Design B seeks to balance usefulness with low added value. Design C is intended to be more efficient and robust than the other two.

4 – Finally, the last activity accomplished was the Concept Selection Matrix construction. The evaluation criteria were defined as the Customer Requirements, already defined in the Informational Phase (Slaviero et al., 2021). Three different designs were evaluated in terms of meeting each requirement using the Likert Scale, with the following values: 1 (does not meet), 2 (mildly meet), 3 (moderately meet), 4 (meets well) and 5 (meets very well). At the end of the table, the importance value of the criteria is multiplied by its meeting value attributed, and then add up the values obtained. Therefore, the selected design will be the one with the highest sum value.

4. RESULTS AND DISCUSSION

4.1 Product Working Structure

As the first step, the product Overall Function was defined as: "Shred different polymers of arbitrary sizes through a safe operation". The overall function was defined using the oriented abstraction process, described by the methodology. This process is indicated to avoid preset or conventional ideas. The next step was to define the system inputs and outputs as "polymer" and "shredded polymer", respectively. Inputs and outputs, energy and system signal refer to the application of forces, conversion, transfer and storage of energy. For example, the input energy comes from the local electrical network, which feeds the mechanisms power source that will perform the overall function, being converted into mechanical energy through the shredding mechanism and finally resulting in the output energy: the deformation and shear of shredded polymers. The result of this process is shown in Figure 2.

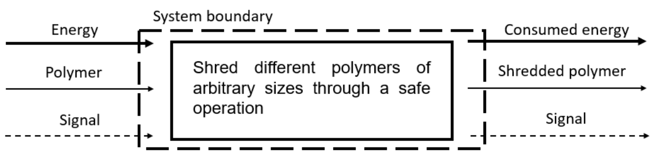


Figure 2 - System's overall function, its inputs and outputs.

The polymer shredder system working structure, splitting the overall function into the respective partial functions, can be seen in Figure 3.

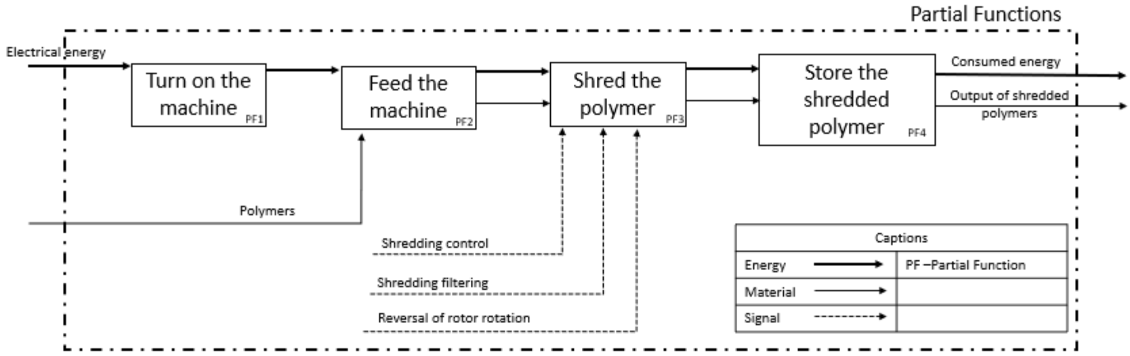


Figure 3. System’s partial functions.

Lastly, partial functions are broken down into more specific functions, called elementary functions. The set of these functions is what makes up the System's Working Structure, in Figure 4.

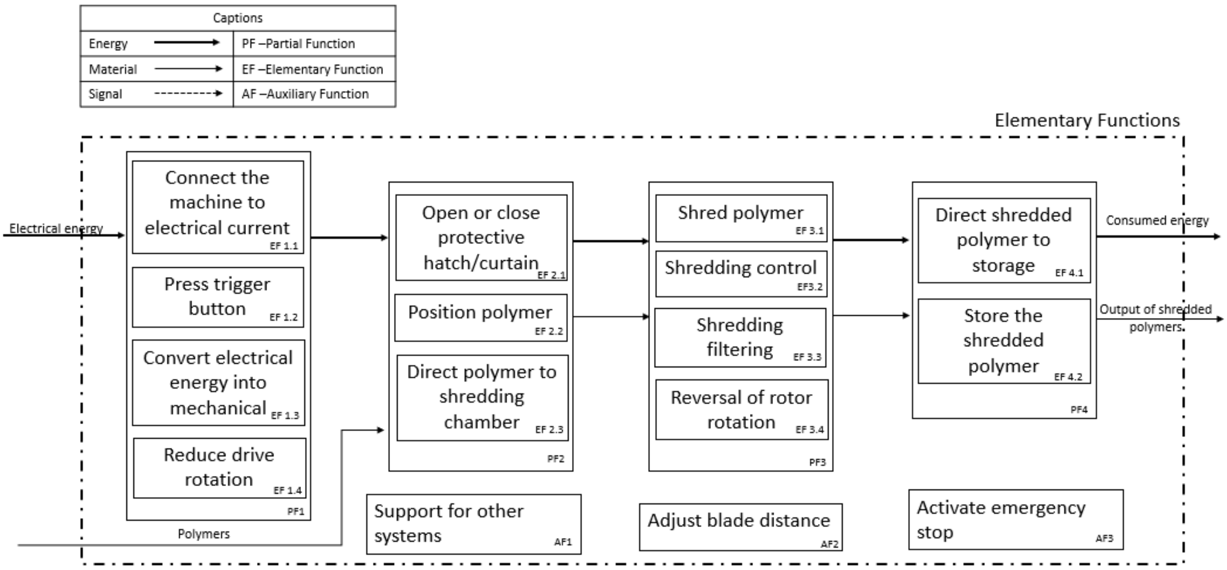
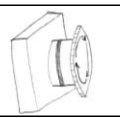
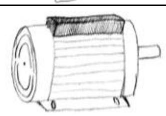


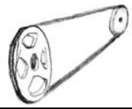
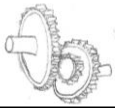
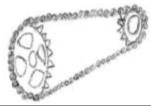
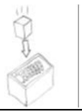
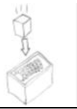
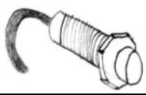
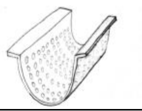
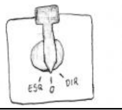
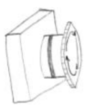
Figure 4. System’s working structure.

4.2 Morphological Matrix of alternative solution principles

The proposed solution principles for each elementary function of the system are described below, and illustrated in the Table 1.

Table 1. Morphological Matrix

Subfunctions \ Solution Principles		1	2	3	4
1	Connect the machine to the electrical current				
2	Press trigger button				
3	Convert electrical energy into mechanical				

4	Reduce drive rotation				
5	Open or close protective hatch/curtain				
6	Position Polymer				
7	Direct polymer to shredding chamber				
8	Shred polymer				
9	Shredding control	**NO COUNTERMEA-SURE**			**SENSOR THAT DETECTS A CURRENT SPIKE**
10	Shredding filtering	**NO SIEVE**			
11	Reversal of rotor rotation			**NO CAPABILITY TO REVERSE ITS ROTATION**	
12	Direct shredded polymer to storage				
13	Store the shredded polymer	**NO CONTAINER**			
14	Support for other systems				
15	Adjust blade distance	**NO ADJUSTMENT**			
16	Activate emergency stop				

Connect the machine to the electrical current: To start the shredding process, first is necessary to supply the machine with a source of electrical energy. The choice of this design depends on the electric motor that will be used. Therefore, two solution principles were elaborated for this: two-phase power cable [1] and three-phase power cable [2].

Press trigger button: After feeding the machine to the electrical network, it is then necessary to release the current through its circuit, to actually turn it on. This step is realized pressing the trigger button, for which there are for solution proposals: a killswitch button [1], rocker switch [2], pressure button [3] and toggle switch [4].

Convert electrical energy into mechanical: The button triggered will transmit electrical energy to the system. A device must convert electrical energy into mechanical, allowing the machine to work. This device must be an electric motor [1].

Reduce drive rotation: The actuator, in this case an electric motor, has a very high rotation for shredding polymers. In this case, it is necessary to couple a speed reduction system, seeking to achieve a final rotation that is more suitable for the product's function. For this purpose, were defined three solution proposals: reduction using pulleys and flat belts [1], using gears [2] and using a rack, pinion and roller chain drive system [3].

Open or close protective hatch/curtain: Then, feed the machine to start the crushing process. The first step is to open the protective hatch or curtain, as this obstructs the passage to the shredding chamber. This item is also responsible for preventing shredded particles from being thrown from the inside to the outside of the machine during the procedure. Three principles of solution were devised for this case: without any protective apparatus [1], hatch (attached by hinges [2] and protective curtain (if the feeding unit is directed horizontally) [3].

Position Polymer: after clearing the passage of the polymer to be crushed, it must be placed on some platform that is safe and at the same time capable of directing it to the shredding chamber. For this purpose, three solution principles were conceived: direct positioning it in the shredding chamber [1], positioning it in a ramp [2] and free fall (object is dropped just above the shredding chamber, moving by gravity) [3].

Direct polymer to shredding chamber: After positioning the polymer, it must be directed to the shredding chamber somehow. The established concepts are: by sliding (hopper) [1] and free fall [2]

Shred polymer: A type of shredding mechanism must be used to process the inserted polymer. Therefore, the following concepts were established: mill (rotating and stationary knives) [1] and shredder (blades arranged on a main shaft) [2]. The system that comprises the shredding mechanism is the shredding chamber.

Shredding control: Some type of sensor or mechanism must monitor the constancy of polymer shredding, so that jams and possible damage to the machine do not occur. For this, some solution principles were defined: no countermeasure [1], optical sensor monitoring constant shaft rotation [2], inductive sensor with the same purpose [3] and sensor that detects a current spike (which occurs when the blades jams) [4].

Shredding filtering: After shredding, the polymer can be filtered according to the desired particle size. In order to meet this, two solution principles were determined: not using a sieve [1] and using a sieve [2].

Reversal of rotor rotation: When detected a jam, rotors must reverse their rotation direction to unclog the shredding mechanism. The solution principles determined were: through the use of a changeover switch ("manual" form) [1], a microcontroller ("automatic" form, depends on the sensor used) [2] and not having this capability [3].

Direct shredded polymer to storage: After being shredded, the polymer must be transported to some form of storage. To meet this requirement, the following solution principles were established: through free fall [1] or a ramp [2].

Store the shredded polymer: Finally, the crushed polymer must be stored somewhere for later use. Therefore, the following concepts were determined: not have any container (requiring something external to the machine frame) [1] or a container attached to the frame, so that it is detachable [2].

Support for other systems: A structure must support the other systems of the product. Two solution principles were determined to meet this requirement: rectangular cross section steel tubes [1] and circular cross section steel tubes [2].

Adjust blade distance: Depending on the shredding mechanism it is possible to adjust the distance between the blades. This attribute offers the operator the advantage of changing the shredded polymer final granulometry. Two solution principles were conceived: No adjustment [1] and positioning by oblong holes [2].

Activate emergency stop: An emergency button must be installed for safety reasons, when necessary to stop the machine operation. For this, the following solution principle was chosen: kill switch [1].

4.3 Alternative Design Concepts

Three product designs were developed using the solution principles matrix. The first of these was designed with the objective of reducing manufacturing costs as much as possible, the second to be practical and affordable and the third features different mechanisms and a more robust design. All designs are detailed in the next subtopics.

4.3.1 Design Concept A

The first design uses a shredder-type shredding mechanism. Its goal is to be the most economically accessible among the three concepts. It features a single-phase motor, only one blade shaft and has a reduced number of elements in its structure. Figure 5 shows its design, together with a breakdown of its feeding unit, shredding unit and structure.

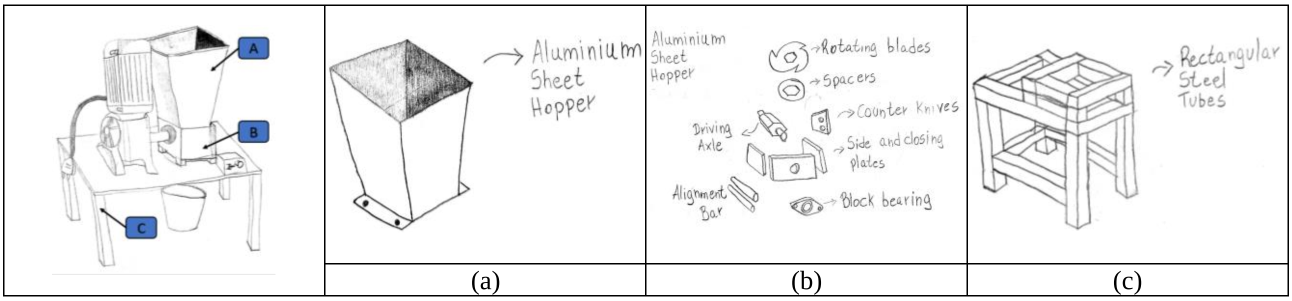


Figure 5. Sketch of Design A and detailing of its feeding unit, shredding unit and structure.

The power cable chosen for this design must be two-phase type. This way, it will be more practical for the home user. This choice limits the electric motors options, as there are models manufactured specifically for three-phase current.

Among the solution principles for the elementary function number 2, the 3-position toggle switch is chosen. Its adoption is in line with the product's purpose of being practical and having an easy understanding of its operation. It does not activate the system in neutral position, and in other positions, different directions of rotation of the axis are activated.

To convert electrical into mechanical energy, a single-phase electric motor will be used. This choice is made with a view to its practicality for the home user, who will be able to use the product at their home or in a small workshop.

The chosen solution principle that serves elementary function number 4 is gear reduction. The reason for this choice is the intention to create a compact and effective product with easy handling.

For elementary function number 5, a open hatch will be used. This solution increases safety, as it prevents the user's hands from getting close to the shredding chamber. But it does not guarantee that the thrown particles will be contained.

To meet elementary function number 6, the solution principle number 3 was chosen. It allows the adoption of best safety practices for the operator, avoiding the approach of their hands to the shredding mechanism. Following the reasoning of the last elementary function, number 7 was also opted for free falling.

The shredding mechanism defined for elementary function number 8 is the shredder type. The main rotor will consist of a shaft, with the blades and spacers coupled to it. No sensor that detects the jamming of the blades was chosen, attending elementary function number 9. The reversal must be activated manually using the toggle switch. Once this process is done, crushing can resume normally. For the shredding filtering, the principle of solution number 1 was defined: not to have a sieve. This decision was made in order to simplify the shredder structure.

To meet the elementary function number 11, the same solution as the elementary function number 3 is used, which is the presence of a toggle switch. Therefore, the reversal of the rotors is performed manually.

To meet the elemental function number 12, to direct the shredded polymer to storage is through free fall.

The form of storage of the shredded polymer, which corresponds to elementary function number 13, presents that the design does not have its own container, requiring an external component for assistance.

The auxiliary function numbers 14 and 15 are met by having a rectangular section tube structure and by not adopting an adjustment. The first item is justified by its availability on the market and its practicality in handling. The second is chosen aiming at the fewest number of components possible, seeking simplicity for building its structure.

Finally, auxiliary function number 16 is met by presenting an emergency stop. This item becomes essential implementation because of the nature of the machine, which is potentially dangerous.

4.3.2 Design Concept B

The second design consists of a shredder-type mechanism for shredding. Its purpose is to have a low added value, yet be effective in its role. It features a single-phase motor and two blade axes, facilitating shredding. The design sketch and details of its feeding unit, shredding unit and structure are presented in Figure 6.

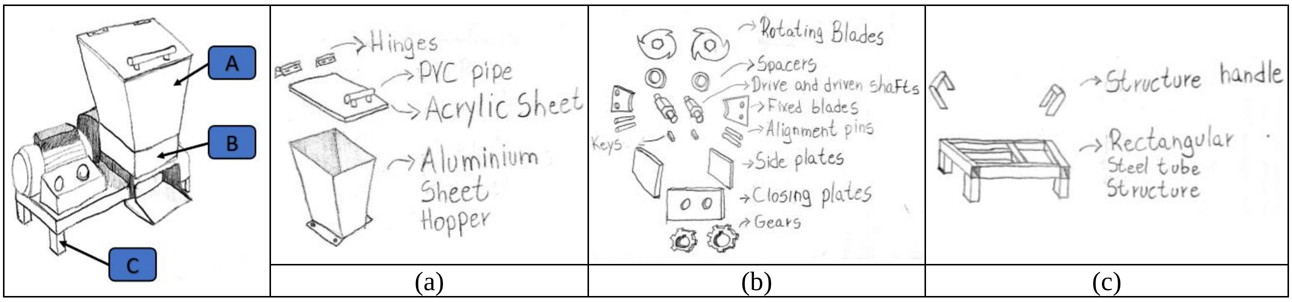


Figure 6. Sketch of Design B and detailing of its feeding unit, shredding unit and structure.

The power cable chosen for this design must be of the two-phase type.

Among the solution principles for elementary function number 2, the pressure button is the simplest. Its adoption is in line with the product's purpose of being practical and having an easy understanding of its operation. For better visibility, a light signal is recommended to represent that the machine is in operation.

To convert electrical into mechanical energy, elementary function number 3, a single-phase electric motor will be used. Like Design A, this choice is made with a view to practicality for the domestic user.

The chosen solution principle that meets elementary function number 4 is gear reduction. The reason for this choice is the intention to create a compact and effective product that facilitates user handling.

For elementary function number 5, the closed-type hatch will be used. This decision was made because of its greater security, compared to the open hatch.

To meet elementary function number 6, the principle of solution number 3 was chosen. It allows the adoption of best safety practices for the operator, avoiding approaching their hands to the shredding mechanism. Following this reasoning, elementary function number 7 was also opted for free fall.

The shredding mechanism defined for elementary function number 8 is the shredder type. This choice was made because of the greater manufacturing practicality compared to the mill type. The main rotor consists of two axes, with blades and spacers coupled to them. To meet elementary function number 9, a sensor that detects a current spike was chosen. A generic term is used because numerous alternatives are available on the market to meet this need. The purpose of this device is to detect a current peak when the shredder blades jams due to excessive accumulation of material, and thus be able to reverse its rotors, clearing the blades. Once this process is done, shredding can resume normally.

For shredding filtering, the solution principle number 1 was chose, that is not to have a sieve. This decision was made in order to simplify its structure. If a smaller particle size is needed, it is possible to reinsert the already shredded polymer.

Among the solution principles for elementary function number 11, it was chosen to use a microcontroller. This decision is in accordance with the choice made to meet the shredding control, as an automated process of reversing the rotors in case of blade jamming is sought.

As for directing of the shredded polymer to storage, elementary function number 12, an exit ramp was chosen. This facilitates transport in a more orderly manner to a container.

In order to meet elementary function number 13, solution principle 1 was chosen: do not have its own container. This way, the operator has free choice about the use of a container to store the shredded polymer.

Like Design A, Design B serves the auxiliary function number 14, having a rectangular-section tube structure. The item is justified by its availability on the market and its practicality in handling.

As for the blades adjustment, which corresponds to elementary function number 15, it was decided not to adopt it. The smallest number of items possible was valued, seeking the simplicity of structure construction.

Finally, the shredder serves elementary function number 16, having an emergency button.

4.3.3 Design Concept C

The third design consists of a mill type shredder mechanism for shredding. The machine has a structure more robust than the others designs. Its purpose is to be more efficient, therefore, it uses a three-phase motor together with a mill-type shredding mechanism. Because of this, it should have a considerably higher manufacture cost compared to other designs. The design sketch, together with the details of its feeding unit, shredding unit and structure, is shown in Figure 7.

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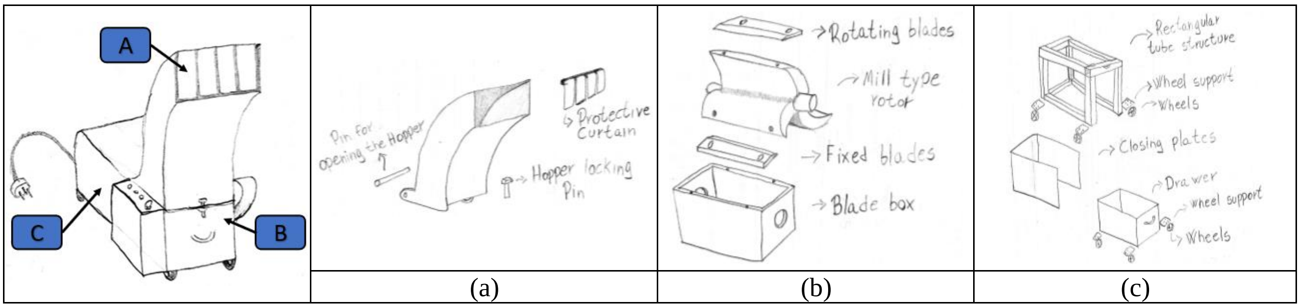


Figure 7. Sketch of Design C and detailing of its feeding unit, shredding unit and structure.

Because of the type of motor required for this design, its power cable will also be three-phase.

It is opted for the pressure button for the elementary function number 2.

Unlike previous designs, the electric motor chosen for this design must be three-phase type. This type of motor usually has greater power than single-phase ones, justifying its choice.

In order to meet elementary function number 4, a set of pulleys and flat belt is chosen to reduce the rotation speed.

To meet elementary function number 5, the protective curtain is opted. Therefore, because of its display, elementary functions 6 and 7 are also defined: the polymer is positioned and directed by a ramp into the shredding chamber.

Given the elementary function number 8, the shredding mechanism is the mill type, as detailed above. This kind of machine does not present any way to control shredding, so the solution chosen for elementary function number 9 is to do not having any sensor. The way to filter the shredding defined to meet elementary function number 10 was to use a sieve.

This kind of machine does not present any form to rotor rotation reversal. Then the solution chosen to elementary function number 11 is to not having the capability to reverse the rotations of its rotor.

To meet the elementary functions number 12 and 13, it was defined that the way to direct the shredded polymer to storage is through free fall, followed by its storage in a proper container.

Its structure will be built by rectangular cross section tubes, to meet elementary function number 14.

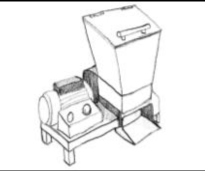
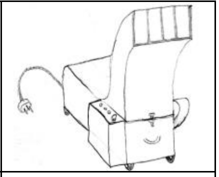
The chosen crushing mechanism allows adjustment of the distance of the blades through oblong holes. So that was the option for auxiliary function number 15.

Finally, like the other designs, an emergency button should be implemented for safety reasons.

4.4 Design Concept Evaluation Matrix

Table 2 presents the evaluation of product designs.

Table 2. Product design concepts evaluation matrix.

Selection Criteria	**Weight**			
		Design A	**Design B**	**Design C**
Roughness	430	4	4	3
Number of Elements in the structure	930	5	4	3
Number of wheels present	315	2	4	5
Allow 2 directions of rotation	796	3	5	1
Available sieve space	305	3	3	5
Mass	722	4	3	1
Reduced number of elementary functions	373	4	4	4
Hopper Length	606	4	4	5
Number of hopper locks	509	2	4	5
Present emergency stop	764	5	5	5
Present motor	1,076	5	5	5
Motor power	491	3	3	5
Feeding nozzle area	410	4	4	5
Number of blade adjustments	629	2	2	4
Noise	519	2	2	4
Price of used materials	1,218	5	4	2
Corrosion rate of materials used	758	4	4	5
Yield strength	560	3	4	5
Total		**43,536**	**44,466**	**43,088**

It is possible to observe that Design B presented a higher score than the other concepts, obtaining 44,466 points. This is justified, as its purpose is to provide a good balance between efficiency and cost. Design C, on the other hand, seeks to present good yield and robustness, but its production cost can leverage its final cost too much, which makes acceptance in the domestic environment unfeasible. Finally, although Design A should be more affordable, it does not meet the other requirements as well as concept B, which makes it scores less. Therefore, it is concluded that concept B presents the best solution according to the defined criteria.

5. CONCLUSION

It was possible to list several solution principles for the sixteen elementary functions defined in the product working structure, thus resulting in designs A, B and C. Design A is designed to be more economically accessible, Design B was developed to have the best cost-benefit ratio, and finally, Design C was developed to have the greatest efficiency in the shredding process. Selection matrix reveals that Design B is the one that best meets the project specifications, reaching 44,466 points, 2.09% higher than design A and 3.20% higher than design B.

The use of a structured NPD is essential for the development of an engineering project. The use of a systematized procedure for the development of an industrial product has the benefit of justified design choices, precision and completeness of each phase of the product design. Therefore, the solutions presented are the closest to the user's needs.

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7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.