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Towards Sustainable Design for Manufacturing and Assembly: An Integrated Approach

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Abstract.

In foundries and construction sites, for example, angle grinders are used for deburring and other high-performance grinding applications. So, this research looks at the angle grinder's sustainable design using DFMA (Design for Manufacturing and Assembly) analysis. A excellent product with a low number of parts and minimal complexity is the result of using the Design for Manufacturing and Assembly (DFMA) approach, which reduces development time and costs. By "sustainability design," we mean a method of creating things that is good for the environment and people equally. This study's sustainability design incorporates DFMA analysis of the manufacturing and assembly phases. Design solutions involve reducing the number of parts and the amount of time it takes to assemble them, independent of manufacturing method choice, materials cost, or other factors. Analyses on angle grinders are carried out using the 3D scanning technique in Catia software for the purpose of designing certain parts, and sustainability analyses are carried out using Solidworks software. These methods are integrated with the Boothroyd and Geoffrey DFMA approach. With 15.34 KgCO2, 2.10×10-2 KgPO4, 15.5 KgSO2, and 1.95 MJ produced in the production of one angle grinder, the present product efficiency is at 21.3%. It is anticipated that all research criteria will be reduced by 25% via this investigation.

INTRODUCTION

Sustainable design must be a part of product creation from the very beginning, beginning with the manufacturing process, and must take into account environmental, social, and economic impact indicators as well as product attributes. Reducing energy consumption, carbon footprint, number of parts, required amount of material, assembly time, and manufacturing costs are sustainability indicators. One process that contributes to good products is DFMA, which is related to sustainable design and aims to minimize the number of parts by decreasing product complexity and economics [1]. Consumption of raw materials, servicing, maintenance, upgrading, and end-of-life (EOL) are all aspects of a product's life cycle that are investigated during sustainability design. The comparison between the redesign product and the old product will be used to demonstrate the reduction of sustainability indicators [1]. Because it incorporates a product's life cycle—the initial activities linked with measuring, evaluating, and improving environmental, economic, and social aspects—the sustainability concept is important in addressing environmental problems such as population growth, resource depletion, pollution, and excessive consumption. [2].

The majority of the research methods center on remanufacturing products or designing them for remanufacturing (DFRem) [2]. In order to evaluate sustainability throughout production, Eastwood and Haapala [3] laid up an approach. Reusing or recycling products is a formal approach in eco-design practice [4]. One approach is DFMA, which makes it possible to cut down on operating time and expenses while also simplifying the product [3, 5]. To create a sustainable design, it is necessary to use the tools in integrating methods, which include DFMA, DFE, and DFRem. Develop a strategy to lessen the negative effect on product development by integrating functional analysis with CAD/CAE tools, sustainability indicators, and DFMA. The engineering approach known as functional analysis and life cycle assessment (LCA) allows engineers to evaluate the effects of various design scenarios, which may save time and physical resources by eliminating the need for trial and error and, in turn, minimize costs and environmental consequences [1].

One way to look at design for production and assembly is as a collection of guidelines for making better goods overall [6]. Goals of DFMA include analyzing management chain costs, improving product quality and simplifying it, and minimizing working time in the design, manufacturing, and procurement departments, all without affecting the product's function. Printing and assembly should be made cheaper [1]. Sustainable development was not a factor in DFMA's analysis and improvement of both the original and current product architecture. According to some, it combines elements of both DFA (design for assembly) and DFM (design for manufacturing) [5]. Evaluation of the wasteful effects of production, upkeep, and disposal [7].The recommended practice in DFMA is to simplify the enclosure and connecting elements, simplify the hanging components, verify the gauges, and simplify the connectors [1].

METHODOLOGY

Case Study

This study about the DFMA and the sustainability design and the process section are used to present the flow of the data collecting. This part describes actions to be taken in investigation the research problem and the rationale for the application of specific procedures or techniques used to identify, select process and analyse data applied to understanding the problem. The figure 1 is the research method that simplify the method use.

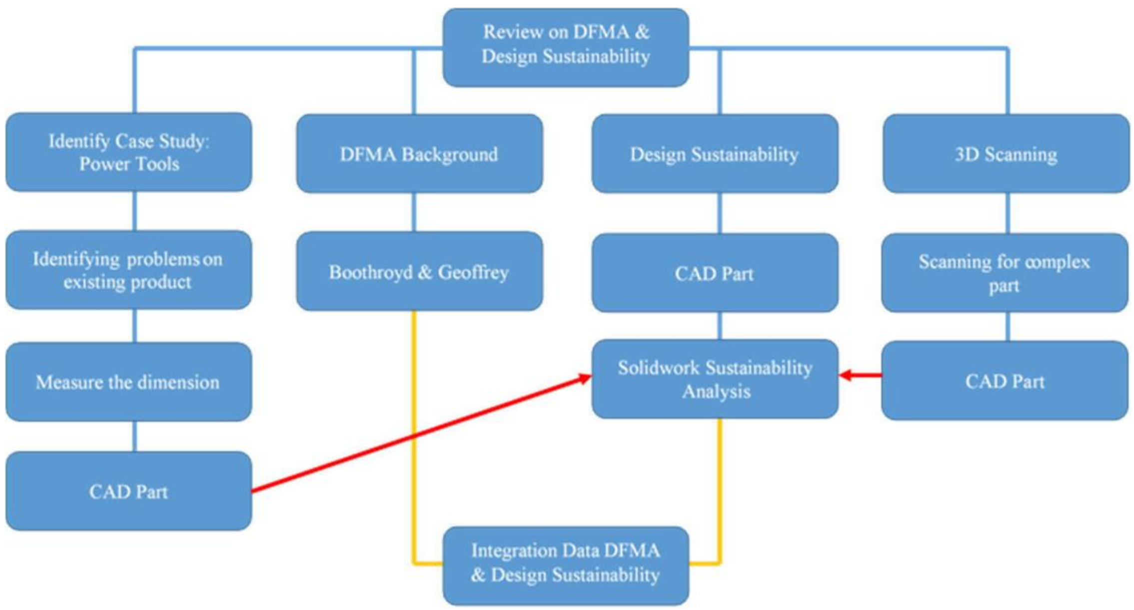

FIGURE 1. Methodology Project Flow Chart

Angle grinder consists of 44 parts which is include the metal and plastic part. The dimension is measure in millimetre and measured part by part and drawing in the Catia and Solidwork software. The DFMA process is applied to this part and the design efficiency and the assembly cost is calculated for this product. The sustainability is measure by using the Solidwork software that include the selection of material and manufacturing detail.

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Design for Assembly (DFA)

DFA is an established as a subset of DFM that involving the minimizing the assembly cost. For most of the products, assembly are contributing relatively in small part of the total cost. However, focusing on the assembly costs yields are strong indirect to the benefits. Often because of the importance on DFA, the overall support cost, manufacturing complexity and parts count are all reduced sideways with the cost of assembly. This section presents a principle that are useful to guide in DFA decisions [8]. DFA may be employed in product reverse engineering or new product development. The primary results of DFA usage are reduced unit costs, shortened manufacturing lead times, and increased reliability. Table 1 show the analysis for the grinder part.

TABLE 1. Result of theoretical part count; Alpha, α and Beta, β

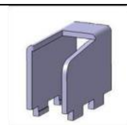
Part No.	Part Name	Part Quantity	Theoretical Part Count	Part Function	α Alpha	β Beta	α+β =
1	 Carbon holder 1	2	2	Holding a carbon and spiral metal plate	360	360	720
2	 Carbon holder 2	2	2	Carbon case and spiral metal blocker	360	360	720
3	 Switch connecter	1	1	Connecting the slider switch the switch in the grinder	360	360	720
4	 Slider Switch	1	1	As a switch to on and off the grinder	360	360	720
5	 Motor cover	1	1	Cover the motor part	360	360	720
6	 Plastic part 1	1	0	Connect to the head part and hold the gear 1	360	360	720
7	 Plastic part 2	1	0	Connect with the plastic part 1	360	180	540
8	 Body	1	1	Motor house and a holder	360	360	720

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TABLE 1. Result of theoretical part count; Alpha, α and Beta, β (Continued…).

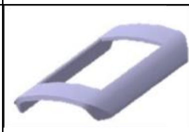
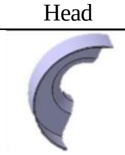
Part No.	Part Name	Part Quantity	Theoretical Part Count	Part Function	α Alpha	β Beta	α+β =
9	 Motor	1	1	To make the grinder rotate	360	360	720
10	 Bearing motor cover	1	1	Cover the bearing that connect to the body part	360	0	360
11	 Coil holder	2	2	Hold the coil that surround the motor	360	360	720
12	 Coil	2	2	Make a electrical connection with the motor to make the angle grinder run	360	180	540
13	 Body cover	1	0	Cover the component that attached to the body part	360	360	720
14	 Head	1	1	Gear house that connect the motor to the blade	360	360	720
15	 Blade cover	1	0	Cover the blade part	360	360	720
16	 Blade cover coupling	1	0	Attached the blade cover to the angle grinder	360	360	720
17	 Blade base	1	0	Attaching the blade to the head part	360	180	540

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TABLE 1. Result of theoretical part count; Alpha, α and Beta, β (Continued…).

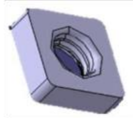
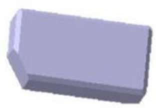
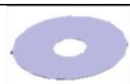
Part No.	Part Name	Part Quantity	Theoretical Part Count	Part Function	α Alpha	β Beta	α+β =
18	 Nut 1	2	0	Attached the carbon holder to the body part	180	90	270
19	 Spiral metal plate	2	2	Push the carbon	360	360	720
20	 Carbon connecter	2	2	Connecter in electrical	360	360	720
21	 Bearing cover	1	0	Cover the bearing that connect to the motor shaft	180	0	180
22	 Gear 1	1	1	Connect the motor to the bevel gear	360	40	400
23	 Switch cover	1	1	Cover the switch box	360	360	720
24	 Screw 1	4	1	Connect the	360	360	720
25	 Screw 2	4	1	Connect the head to the body	360	360	720
26	 Screw 3	1	0	Hold the wire at the body	360	360	720
27	 Screw 4	1	0	Connect the body and the cover	360	360	720

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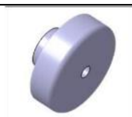
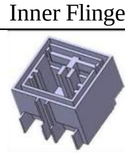
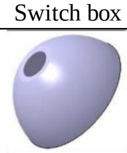
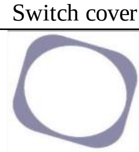
TABLE 1. Result of theoretical part count; Alpha, α and Beta, β (Continued…).

Part No.	Part Name	Part Quantity	Theoretical Part Count	Part Function	α Alpha	β Beta	α+β =
28	 Screw 5	2	0	Connect the switch to the body	360	360	720
29	 Screw 6	2	0	This screw connects the carbon holder to the part body	360	360	720
30	 Bevel Gear Holder	1	1	Hold the bevel gear	360	360	720
31	 Bevel Gear	1	1	Connect from motor gear	360	360	720
32	 Push Button Cover	1	0	Cover the push button	360	0	360
33	 Push Button	1	0	Stop the grinder	360	0	360
34	 Inner Flinge	1	1	Connect the wheel to grinder	360	180	549
35	 Switch box	1	1	Connect the electric to grinder	360	360	720
36	 Switch cover	1	0	Cover the switch	360	0	360
37	 Flinge	1	0	Cover the head and bevel gear holder	180	90	270
	Total	52	27				

The design efficiency is the metrics design that expressed as a cost function that will help to reduce the overall number of components by focusing the design team's attention on the need of each part and it fill define the design handling and assembly time that affect the cost of the product assembly as show in table 2.

TABLE 2. Estimation Assembly Time for Parts

No.	Part Name	α+β =	Manual Handling Code	Manual Handling Time (s)	Manual Insertion Code	Manual Insertion Time (s)	Assembly Time (s)	Assembly Cost (RM)
1	Carbon holder 1	720	31	2.25	92	5	14.5	0.038
2	Carbon holder 2	720	32	2.7	91	7	19.4	0.050
3	Switch connecter	720	33	2.51	03	3.5	6.01	0.016
4	Slider Switch	720	30	1.95	30	2	3.95	0.010
5	Motor cover	720	30	1.95	00	1.5	3.45	0.009
6	Plastic part 1	720	30	1.95	00	1.5	3.45	0.009
7	Plastic part 2	540	30	1.95	00	1.5	3.45	0.009
8	Body	720	30	1.95	31	5	6.95	0.018
9	Motor	720	30	1.95	00	1.5	3.45	0.009
10	Bearing motor cover	360	10	1.5	00	1.5	3	0.008
11	Coil holder	720	30	1.95	01	2.5	4.45	0.012
12	Coil	540	30	1.95	91	7	8.95	0.023
13	Body cover	720	30	1.95	30	2	3.95	0.010
14	Head	720	30	1.95	31	5	6.95	0.018
15	Blade cover	720	30	1.95	30	2	3.95	0.010
16	Blade cover coupling	720	30	1.95	31	5	6.95	0.018
17	Blade base	540	20	1.8	00	1.5	3.3	0.009
18	Nut 1	270	64	6.80	12	5.0	23.6	0.061
19	Spiral metal plate	720	36	3.06	90	4	7.06	0.018
20	Carbon connecter	720	31	2.25	96	12	14.25	0.037
21	Bearing cover	180	07	2.65	00	1.5	4.15	0.011
22	Gear 1	400	15	2.25	31	5	7.25	0.019
23	Switch cover	720	33	2.51	31	5	7.51	0.020
24	Screw 1	720	64	6.80	12	5.0	47.2	0.122
25	Screw 2	720	64	6.80	12	5.0	47.2	0.122
26	Screw 3	720	64	6.80	12	5.0	11.8	0.031
27	Screw 4	720	64	6.80	12	5.0	11.8	0.031
28	Screw 5	720	64	6.80	12	5.0	23.6	0.061
29	Screw 6	720	64	6.80	12	5.0	23.6	0.061
30	Bevel Gear Holder	720	30	1.95	92	5.0	6.95	0.018
31	Bevel Gear	720	30	1.95	92	5.0	6.95	0.018
32	Push Button Cover	360	15	2.25	40	4.5	6.75	0.017
33	Push Button	360	16	2.57	40	4.5	7.07	0.018
34	Inner Flinge	540	20	1.8	30	2.0	3.8	0.010
35	Switch box	720	30	1.95	30	2.0	3.95	0.010
36	Switch cover	360	16	2.57	30	2.0	4.57	0.012
37	Flinge	270	09	2.98	06	5.5	8.48	0.022
						Total	383.65	0.995

Total assembly cost = RM 0.951
Total theoretical part count = 26
Total assembly time = 366.65

$$DFA\ index = \frac{(Theoretical\ minimum\ number\ of\ parts)\times(3\ seconds)}{Estimated\ total\ assembly\ time} \qquad (1)$$

= 21.3%

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DFM and Sustainable Analysis

A product's production cost is the economic success factor [8]. The manufacturing cost and the selling procedure have differing effects on the profit margin. Assuring excellent product quality while minimizing manufacturing cost is the key to successful affordable design. Effective DFM practice guides to low production costs without sacrificing product quality, making it one of the methods for accomplishing this aim. Reducing environmental effect while simultaneously improving company efficiency and saving money in the long run is the goal of sustainable design. The carbon footprint associated with the manufacturing process and the use of raw materials account for the largest portions of a product's environmental effect [9]. A sustainable development is one that meets the requirements of the present without compromising those of future generations [10]. Life cycle assessment (LCA) is now a thorough method for assessing environmental sustainability. From extraction to disposal, transportation, and production, the whole process was examined. Additionally, it delves into the overall power consumption that occurs during the development process. You can see the results of the sustainability study in table 3.

TABLE 3. DFM and Sustainable analysis on grinder part.

No	Part name	Material	Manufacturing Process	Weight (g)	Carbon Footprint ($KgCO_2$)	Water Eutrophication ($KgPO_4$)	Air Acidification ($KgSO_2$)	Total Energy Consumed (MJ)
1	Carbon holder 1	1023 Carbon Steel Sheet (SS)	Stamped/Formed Sheetmetal	3.33	0.012	1.9E-6	2.9E-3	0.152
2	Carbon holder 1	1023 Carbon Steel Sheet (SS)	Stamped/Formed Sheetmetal	2.03	7.1E-3	1.2E-6	1.8E-3	0.093
3	Switch connecter	PBTP	Injection Molded	4.16	0.035	8.9E-6	8.4E-3	0.595
4	Slider Switch	PPE	Injection Molded	1.80	0.016	6.4E-6	7.2E-5	0.281
5	Motor cover	PA Type 6	Injection Molded	13.97	0.183	3.0E-5	0.032	2.9
6	Plastic part 1	PA Type 6	Injection Molded	13.98	0.183	3.0E-5	0.032	2.9
7	Plastic part 2	PA Type 6	Injection Molded	8.29	0.108	1.8E-5	0.019	1.7
8	Body	PA Type 6	Injection Molded	107.83	1.4	2.3E-4	0.243	23
9	Motor	AISI 4340 Steel, normalized	Milled	557.62	2.3	2.1E-3	0.731	28
10	Bearing motor cover	Natural Rubber	Custom	0.88	5.5E-3	1.0E-5	5.3E-3	0.027
11	Coil holder	AISI 304	Milled	132.45	0.897	6.0E-3	0.247	9.9
12	Coil	Gray Cast Iron (SN)	Die Casted	50.00	0.119	8.9E-5	6.8E-4	1.2
13	Body cover	PA Type 6	Injection Molded	69.72	0.911	1.5E-4	0.157	15
14	Head	201 Annealed Stainless Steel (SS)	Die Casted	710.00	7.3	0.011	0.059	86
15	Blade cover	Gray Cast Iron	Sand Casted	90.00	0.213	1.6E-4	1.2E-3	2.1
16	Blade cover coupling	Gray Cast Iron	Sand Casted	40.00	0.087	6.5E-5	5.0E-4	0.868
17	Blade base	AISI 304	Milled	30.00	0.188	6.1E-4	1.0E-3	2.1
18	Nut 1	Galvanized Steel	Milled	0.40	1.5E-3	6.2E-7	6.4E-6	0.021

TABLE 3. DFM and Sustainable analysis on grinder part (Continued…).

No	Part name	Material	Manufacturing Process	Weight (g)	Carbon Footprint ($KgCO_2$)	Water Eutrophication ($KgPO_4$)	Air Acidification ($KgSO_2$)	Total Energy Consumed (MJ)
19	Spiral metal plate	AISI 304	Stamped/Formed Sheetmetal	2.13	0.013	4.6E-5	6.0E-5	0.150
20	Carbon connecter	Plain Carbon Steel	Forged	4.35	0.015	7.3E-6	9.1E-5	0.186
21	Bearing cover	Alloy Steel	Stamped/Formed Sheetmetal	0.47	1.7E-3	1.4E-6	7.9E-6	0.022
22	Gear 1	Cast Alloy Steel	Milled	9.70	0.040	3.1E-5	2.4E-4	0.489
23	Switch cover	PA Type 6	Injection Molded	1.25	0.016	5.1E-6	5.7E-5	0.263
24	Screw 1	Galvanized Steel	Milled	1.30	8.7E-3	4.9E-6	9.7E-5	0.095
25	Screw 2	Galvanized Steel	Milled	1.80	6.4E-3	2.7E-6	2.4E-5	0.087
26	Screw 3	Galvanized Steel	Milled	2.25	8.7E-3	3.5E-6	3.6E-5	0.118
27	Screw 4	Galvanized Steel	Milled	1.49	5.8E-3	2.3E-6	2.4E-5	0.078
28	Screw 5	Galvanized Steel	Milled	0.73	2.8E-3	1.1E-6	1.2E-5	0.038
29	Screw 6	Galvanized Steel	Milled	0.91	3.5E-3	1.4E-6	1.5E-5	0.048
30	Bevel Gear Holder	PA type 6	Injection Molded	30.00	0.200	1.0E-4	1.4E-3	3.2
31	Bevel Gear	1060 Alloy	Milled	60.00	0.806	1.9E-4	5.7E-3	9.9
32	Push Button Cover	PA Type 6	Injection Molded	0.42	5.5E-3	1.7E-6	1.9E-5	0.088
33	Push Button	1060-H18 Rod (SS)	Milled	0.90	0.013	3.0E-6	9.0E-5	0.159
34	Inner Flinge	Brass	Stamped/Formed Sheetmetal	40.00	0.230	7.5E-5	1.4E-3	3.2
35	Switch box	PA Type 6	Injection Molded	4.4	0.060	2.2E-5	2.0E-4	0.918
36	Switch cover	Natural Rubber	Custom	9.2E-5	7.3E-4	2.1E-6	1.1E-5	3.8E-3
37	Flinge	Alloy Steel	Milled	1.5	7.4E-3	5.8E-6	4.5E-5	0.092
		Total		1994.16	15.3422	2.10E-02	1.55E+00	1.95E+02

The data collecting from the 3D scanner machine is save into stl format and import to Catia using a ‘generative shape design’ command in shape section. Then, using the line ‘planar section’ command, the curve line is make through the 3D part. Using the command ‘curve from scan’, convert the planar section to the curve. The few best curves are choosing to make a reference for sketching of the part line. The part is define using the ‘multi section solid’ command to get the rough shape of the product. Finally, the using the part design command in the mechanical design section, the part is finish to the real design. The figure 2 is illustrate the step picture in finish the part design from the 3D scanning data.

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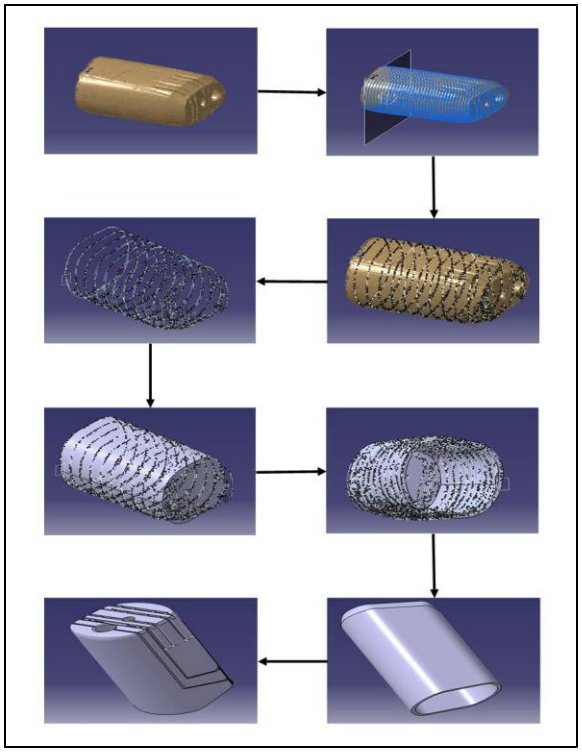

FIGURE 2. Step in the part design from the 3D scanning data.

DISCUSSION

Simplifying, reclaiming, and standardizing relevant information in order to match or improve upon current processes and products might lessen the active component's consumption. To top it all off, DFM practice is making it easier to include manufacturability. The goal of DFM is to find a product idea that is simple to manufacture by integrating the product's design with the process and concentrating on its components. Design for fabrication (DFM) guidelines include creating parts with as little variance as possible, making them multifunctional, designing with as few parts as possible, and making sure they are straightforward to construct. Every product leaves an environmental mark. In order to create a more sustainable society, DFE provides companies with a realistic strategy for limiting effects. The specialists of DFE discovered that, similar to the DFM approach, DFE practice may maintain or improve product quality while minimizing costs and reducing environmental consequences. Product environmental implications include things like energy usage, gas emissions, liquid discharges, and the creation of solid waste. The two main types of effects, material and energy, reflect the most pressing environmental issues that need attention. When most people talk about the energy issue, they usually intend to make something that uses less energy or uses renewable energy.

CONCLUSION

This research suggested using the DFMA approach in conjunction with sustainable design principles. Though it doesn't address every sustainability effect, the DFMA may assist simplify products and save costs in process development, which might contribute to greener manufacturing. Reducing the number of parts has a direct effect on decreasing the assembling time. By shortening the time it takes to disassemble the product, we may improve its End of Life (EOL) by making it easier to dispose of, recycle, and reuse its components. A reduction in Pugh complexity, assembly time, energy consumption per unit of mass, and material mass may also be helpful. 3D scanning provided the data needed to draw the grinder's critical parts in CATIA, which aided in the analysis of the product's sustainability impact. The DFMA method led to the redesign of the grinder, which yielded a more efficient design with fewer parts and less complexity, leading to a more sustainable product.

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