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# IS HYBRID ADDITIVE MANUFACTURING THE BEST OPTION COMPARING COST, QUALITY, PRODUCTIVITY AND FLEXIBILITY? A CASE STUDY USING BIG AREA ADDITIVE MANUFACTURING (BAAM) AND FUSED FILAMENT FABRICATION (FFF) FOR A BEARING MANUFACTURING

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**Abstract.** Hybrid additive manufacturing aims to combine the flexibility of additive processes with the high productivity and quality of material removal processes. However, when combining these three decision factors with the final cost of the part, how does the decision-making process change? In this study, two additive manufacturing processes were chosen as case studies for producing a standard part: fused filament fabrication (FFF) and big area additive manufacturing (BAAM). These parts were manufactured using four different combinations of these processes, with or without machining in the same setup. The conditions were: FFF process, machining (milling and drilling), hybrid additive manufacturing with BAAM and machining and additive manufacturing with FFF and machining. The results were evaluated by comparing manufacturing time, cost, material volume, dimensional tolerances, surface roughness, and flexibility (setup time). Under the evaluated conditions, hybrid additive manufacturing with BAAM presented the best results balancing all proposed criteria, with the lowest cost and material volume consumption, while maintaining similar dimensional and surface quality compared to the other processes. FFF represents the most flexible additive manufacturing process, with the shortest setup time for preparation. Machining had the shortest manufacturing time, due to its high removal rates in the evaluated case. It is expected that these results and discussions will support the composition of other cases for a balanced evaluation of the performance of hybrid additive manufacturing processes.

**Keywords:** big area additive manufacturing, hybrid additive manufacturing, fused filament fabrication (FFF), manufacturing performance indicator

## 1. INTRODUCTION

Manufacturing have been changed over the years to fulfills more challenging competition factors. Once centered in the cost and productivity aspects, such important economical processes have been tailored to achieve even more complex performance indicators. (Chu et.al., 2016). For instance, sustainability pushes manufacturing for a balance force among financial, environmental, and social aspects, pushing the processes engineers to evaluate and design the production looking for alternatives that meets such complicated situation. Additive manufacturing, or also know as “3D printing” represents one of the promising novel production alternatives to meet this balance (Yosofi et.al., 2019). In Figure 1, adapted from Chu et.al. (2016), the historical evolution of manufacturing and the paradigm shifts is briefly described. Over the 1975s, the new trends regarding flexibility, customization and sustainability are the main factors that pushes for design changes, from the “traditional” design for manufacturing (DFM) strategy to a manufacturing for design (MFD).

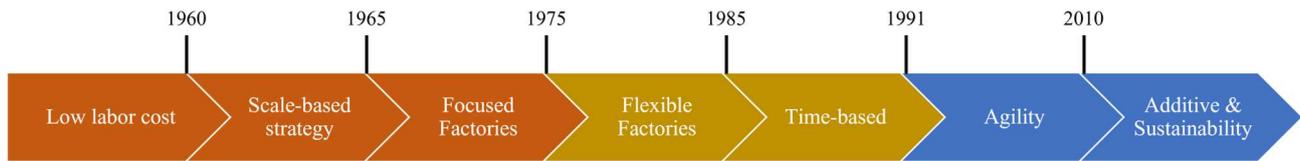


Figure 1. Manufacturing paradigms over the years, *ADAPTED* from Chu et.al. (2016).

The main purpose among the MFD concept is that manufacturing should be used as a design tool to improve the design of a product and thus increase its viability in today’s markets. Therefore, manufacturing processes should be tailored to achieve cost, productivity, quality, and flexibility balance based on the particular case of application.

In this work, a case study is presented to apply these design and performance criteria under the novel manufacturing capabilities of the additive and hybrid additive processes. The main objective is to support further discussions to the use of MFD paradigm. In the following section more details regarding the additive and hybrid additive processes to be evaluated is presented.

## 2. SELECTED MANUFACTURING PROCESSES: ADDITIVE MANUFACTURING AND HYBRID ADDITIVE MANUFACTURING

### 2.1 Additive manufacturing process – fused filament fabrication (FFF)

According to the ABNT NBR ISO/ASTM 52900 (2018) standard, additive manufacturing is a general term for processes that create parts through the successive addition of material. This process can be applied to meet engineering needs as well as in other sectors of society such as architecture, medicine, education, entertainment, among others. Furthermore, according to the standard, the additive manufacturing process by extrusion is the one in which the material is selectively deposited through a nozzle (Associação Brasileira de Normas Técnicas, 2018).

The process of fuse filament fabrication (FFF), commonly used in desktop equipment, involves pulling a continuous filament of larger diameter through a specific diameter hole (nozzle), which is connected to a heating system. This assembly, is briefly described in Figure 2, consisting of the nozzle (8) and the hotend system (4), is known as the extruder, and its purpose is to melt the material, which is expelled through the nozzle due to the pressure applied by the filament tractor (3). To create the part, the build plate moves along the X and Y axes according to the part's geometry, and then the Z axis is typically lowered, providing the layer height. The filament (2) is storage in a spool (1). The part (5) is produced using the combination of the extrusion volume and the movement in the X and Y in each Z level, or layer height. The bed (7) is responsible for attaching the first layer, can be heated to overcome the material contraction effect. In case needed, support structures (6) can be used to achieve higher overhangs.

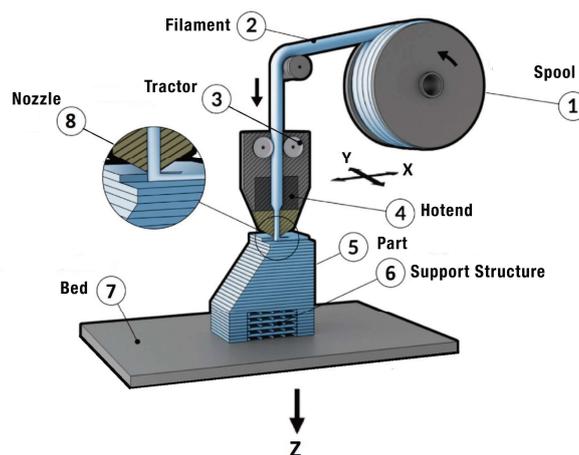


Figure 2. Fused Filament Fabrication extrusion system, *ADAPTED* from Manufacturing Guide.

### 2.2 Additive manufacturing process – big area additive manufacturing process (BAAM)

Another option to produce thermoplastic additive parts is the use of pellets instead of the spool/filament as the material storage. When using pellets in the additive manufacturing process, the construction of the print head has significant differences. It operates with a screw for material extrusion, like those used in extrusion machines. It has a continuous feeding inlet for the pellets and a material heating cylinder. This cylinder is elongated to ensure complete melting of the

material before reaching the extrusion nozzle. Unlike filament-based models, this technology is not commonly and commercially available for desktop machines due to the size of the print head. It is generally employed when high material flow is desired and for manufacturing large-sized parts (Gonzales-Gutierrez, 2018 and Valkenaers, 2013). The description of the extrusion head is describe in Figure 3.

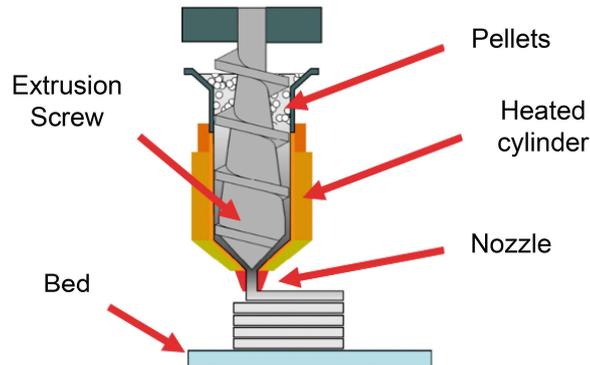


Figure 3. Big Area Additive Manufacturing extrusion head, *ADAPTED* from Gonzales-Gutierrez, 2018.

The main advantage of BAAM compared to FFF is the cost of raw materials and manufacturing time. The screw extrusion system allows for a high deposition rate, which is mandatory for BAAM to produce larger parts. This significantly reduces production time and lowers production costs. With this process, it is possible to reduce production costs by 17 times and production time by 50 times. In addition to this fact, the raw material cost is much lower, given that the price per kilogram of pellets is lower than post-processing in filament form (Nieto, 2020 and Post, 2016).

### 2.3 Hybrid additive manufacturing – additive and CNC machining

Hybrid manufacturing consists of the union of two or more manufacturing processes to produce a part, under the same setup. In this work, the hybrid set combination selected is additive manufacturing (BAAM) with subtractive (CNC machining). The main objective is to join the precision of machining with the freedom of form of additive manufacturing (Nieto, 2020, Post, 2016 and Barbosa, 2019).

In hybrid additive manufacturing, a part is typically built using additive manufacturing methods to create the basic desired shape of the final part. It is then followed by subtractive processes that remove excess material, refine the surface finish and accurately achieve final dimensions. By combining these processes, manufacturers can take advantage of the design freedom and complexity offered by additive manufacturing, while also leveraging the capabilities of subtractive methods (Lalegani Dezaki, 2022 and Riviere-Lorphevre, E, 2023).

Hybrid additive manufacturing offers the possibility of reducing long setup times, errors in fixing parts in devices, since once the part has been produced using the additive method, it will be able to use the same positioning for material removal, reducing operator interference. in the process (Barbosa, 2019).

Integrating additive and subtractive processes in hybrid manufacturing offers advantages. First, it allows the production of parts with complex geometries that would be challenging or impossible to manufacture with traditional methods alone (Barbosa, 2019). Additive manufacturing allows for the creation of complex internal features, bosses and custom structures. Second, hybrid manufacturing can improve efficiency by reducing material waste. Additive manufacturing adds material selectively where needed, rationing the amount of material that needs to be removed in subsequent subtractive processes (Near Net Shape). In addition, it offers the potential for increased productivity and faster response times.

Hybrid manufacturing finds applications across multiple industries, including aerospace, automotive, medical, and tooling. It is particularly beneficial in situations where high-performance materials, complex designs and functional customization are required. By leveraging the capabilities of additive and subtractive techniques, hybrid manufacturing opens up new possibilities for creating innovative and optimized parts (Chu, 2016).

## 3. THE PROPOSED CASE – BEARING HOUSING

The main objective of this work is to compare the three additive manufacturing strategies into the selected four main performance indicators: cost, productivity (time), quality and flexibility. Thus, a bearing housing part was selected as the case study, a commonly used product in manufacturing equipment. The part design is based on a commercial product from HIWIN (Hiwin, 2019), a reference company in automation parts supplier. In Figure 4 the general design is presented, also the representation of the required raw material considering CNC milling, as the main manufacturing process.

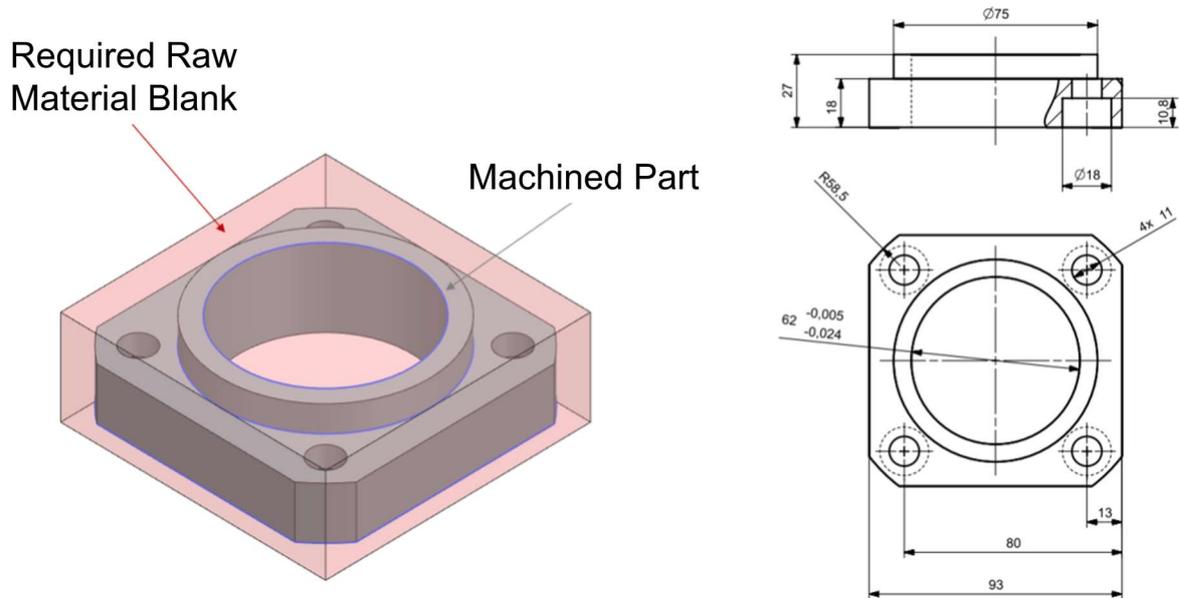


Figure 4. Case study - Hiwin FF 30 based bearing housing and CNC milling assembly.

The bearing housing was produced using four (4) different manufacturing strategies, using same material and under the bearing fit quality requirement for integral housing applications: dimensional tolerances (-0,005mm/-0,024mm) and surface roughness ( $Ra \leq 3,2\mu m$ ) (NSK, 2023). The material selected for the cases was Braskem polypropylene FL900PP-CF, in pellets (for BAAM) and filament (for FFF) form. This polypropylene grade was developed for additive manufacturing applications, with carbon fiber filler to control the material flow and enhance the main mechanical properties (Braskem, 2023). Each manufacturing strategy and its materials and methods are detailed in the next sections.

### 3.1 Manufacturing scenario #1 – fused filament fabrication bearing housing

The bearing housing was designed in the Siemens NX software, exported in the stereolithography extension (.stl) to be used in the FFF slicing software. The slicer selected was Simply3D, already used by the authors and commonly used in FFF applications. The layer and infill strategy were selected with the main objective to produce a solid part, thus, possible to compare quality aspects with the other manufacturing scenarios. Therefore, main process settings are listed and briefly described in Table 1. The FFF machine selected is the Ender 3 model, from Creality, a prototyping 3D printer. This model was selected since it achieves the standard dimensional tolerancing and have low printing cost. As a result, is expected a low-cost additive manufacturing process, without the required dimensional tolerancing and roughness for the bearing fit, requiring additional finishing to achieve the results, and high manufacturing time. However, it is expected to be the more flexible manufacturing option once no setup is necessary and changes in design can be easily made.

Table 1. Experimental setting for the FFF bearing housing fabrication.

FFF Process Setting	Value	Description
Nozzle diameter	0,6 mm	Value based in the Braskem datasheet recommendation (min. value)
Layer height	0,4 mm	Selected under nozzle diameter constraint and to obtain a solid part
Top / Bottom layers	3 and 3	Recommended for better surface quality and solid part
Perimeter shells	3	To achieve the more precision in the external and internal circular holes
Extrusion width	0,6 mm	As a result of layer height, printing speed and nozzle diameter
Printing speed <sup>(1)</sup>	35 mm/s	Value based in the Braskem datasheet and machine limits
Extruder temperature	250 °C	Value based in the Braskem datasheet recommendation
Bed temperature <sup>(1)</sup>	Room temperature	Recommendation for PP material and selected bed adhesive solution
Cooling	100 %	Value based in the Braskem datasheet recommendation
Infill percentage	100 %	Strategy to obtain a solid part, using +/-45° orientation pattern

<sup>(1)</sup> first layer produced using 60% of the printing speed and heated bed at 100 °C for bed adhesive solution best results

### 3.2 Manufacturing scenario #2 – CNC machined bearing housing

The bearing housing design developed in Siemens NX CAD software was used in NXCAM to generate the machining strategies and the GCODE program for the CNC machine tool. The adopted machining strategies were carried out considering the maximum productivity as established by the tool manufacturer for the PP-CF material. The bearing housing was manufactured in two stages, first side and second side, being necessary to turn the part for machining on the other side, both with roughing and finishing stages. The tools used and the main machining parameters are listed in Table 2. The CNC used was a ROMI D800 Hybrid machining center with 3 axes, with FANUC Series 31i-Model B5 control. This equipment was used due to its ability to reach the desired dimensional tolerances and machine hour cost compatible with the market. As a result, it is expected that this process has the shortest manufacturing time and guarantees the dimensional tolerancing and roughness required for the final bearing housing. However, this process will require a larger stock of material, in case there is a change in the geometry of the manufactured part and greater waste of raw material due to machining from a blank.

Table 2. Experimental machining setting for the CNC machined bearing housing fabrication.

Tool	First Side		Second Side	
	Roughing	Finishing	Roughing	Finishing
<b>Face Milling Cutter</b> F4033.B22.050.Z04.06 and Insert SNHX1205ANN-K88 WK10 Z=4	Operation - Face Milling; Vc=501 m/min; f=2947 mm/min; n=3189 rpm; ap=2,5 mm; fz=0,231mm; ae=47mm	Operation - Face Milling; Vc=501 m/min; f=2947 mm/min; n=3189 rpm; ap=0,5 mm; fz=0,231mm; ae=47mm	Operation - Face Milling; Vc=501 m/min; f=2947 mm/min; n=3189 rpm; ap=1,0 mm; fz=0,231mm; ae=47mm	Operation - Face Milling; Vc=501 m/min; f=2947 mm/min; n=3189 rpm; ap=0,5 mm; fz=0,231mm; ae=47mm
<b>Solid carbide shoulder/slot mill MC232-20.0W3B- WJ30 ED Z=3</b>	Operation – Shoulder Milling; Vc=104 m/min; f=715 mm/min; n=1655 rpm; ap=10 mm; fz=0,231mm; ae=9mm	Operation – Shoulder Milling; Vc=153 m/min; f=578 mm/min; n=2435rpm; ap=15 mm; fz=0,079mm; ae=9mm	N/A	N/A
<b>Center Drill</b> Dormer A242 diameter 2.5 mmx8 mm	Vc=14m/min; n=707rpm; f=578 mm/min	N/A	N/A	N/A
<b>Twist drill</b> type N Dormer A114 Ø11mm	Vc=14m/min; n=405rpm; f=578 mm/min	N/A	N/A	N/A
<b>Solid carbide shoulder/slot mill MC232-08.0W3B- WJ30 ED Z=3</b>	N/A	N/A	Pocket milling; Vc=100 m/min; f=692 mm/min; n=1655 rpm; ap=4 mm; fz=0,058mm; ramp angle=6,24°	N/A

### 3.3 Manufacturing scenario #3 – hybrid additive manufacturing bearing housing (BAAM + CNC machining)

The bearing housing was designed in Siemens NX software using the Near Net Shape concept, as shown in Figure 5, with a projected part slightly larger than the desired dimension. This strategy was adopted to save material and machining time, since the pre-form will be manufactured by additive manufacturing and will later go through the machining process, which is the basic concept of the hybrid process.

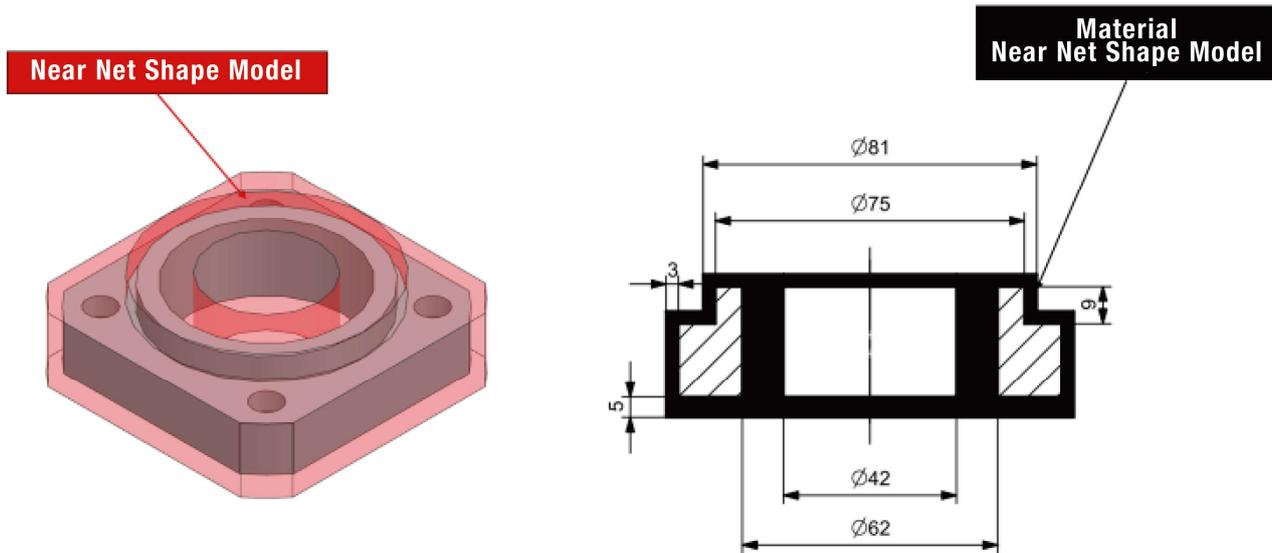


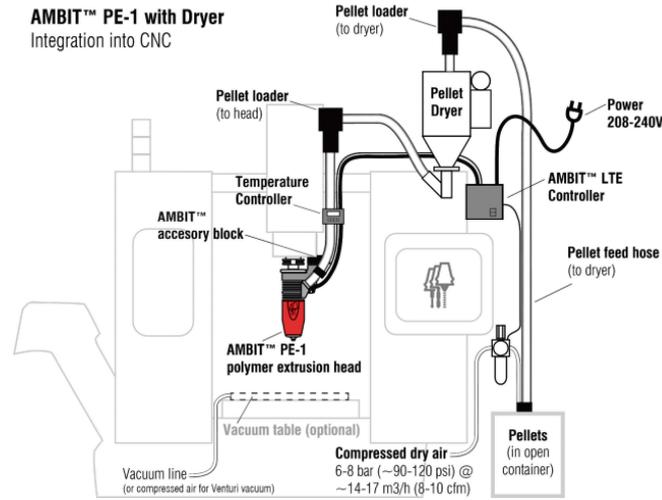
Figure 5. Bearing Housing and CNC milling assembly using Near Net Shape concept.

The part was exported in stereolithography extension (.stl) to be used in the slicing software. The slicer selected was the ORNL Slicer 2, developed by Oak Ridge National Laboratory for BAAM applications. The layer and fill strategy was established to produce a solid part, as manufactured by FFF. Two fabrication strategies were adopted to reduce the deposition time. At the base of the piece, a higher deposition rate was adopted, as it has a larger area which would allow enough time for the layers to cool down and at the top, cylindrical part, the value was reduced to have a minimum time above 30 seconds. Process configurations are listed and briefly described in Table 3, presenting the different values for the square down side (base) of the bearing housing and the cylindrical upper side (top).

Table 3. Experimental setting for the BAAM bearing housing fabrication.

FFF Process Setting	Value (base)	Value (top)	Description
Nozzle diameter	3 mm	3 mm	Default Head AMBIT-PE1
Layer height	2 mm	2 mm	Selected under nozzle diameter constraint
Top/Bottom layers and Perimeter shells	none	none	Wasn't used for this application
Extrusion width	3 mm	3 mm	As a result of layer height, printing speed and nozzle diameter
Printing speed	80,35 mm/s	40,16 mm/s	Value based in the desired material flow rate and minimum layer time of 30 seconds
Extruder speed	160 rpm	80 rpm	Extruder rotation to maintain constant material flow
Extruder temperature	185 °C	185 °C	Best condition for additive manufacturing
Bed temperature	Room temperature	Room temperature	Recommendation for PP material and deposition on fixed PP sheet on vacuum table
Infill percentage	100 %	100 %	Strategy to obtain a solid part, using +/-45° orientation pattern

The ROMI D800 Hybrid equipped with an AMBIT-PE head was used, the material used was Braskem GR900-CF pellet. The part was produced on a fixed PP sheet attached to the machine using a vacuum table, where the additive and further subtractive operations were performed, as shown in Figure 6. For machining, the parameters adopted were the same as for the fully machined part (scenario #2). As a result, it is expected that the deposition time will be much shorter than the FFF additive manufacturing process, however, the total manufacturing time will be longer than that of the part manufactured entirely by machining. The part must present dimensional tolerance and surface finish within the required for bearing application due to the machining process.



Overview of AMBIT™ PE-1 with ancillaries (including pellet dryer) shown on vertical CNC

Figure 6. Overview of AMBIT™ PE-1 with ancillaries (including pellet dryer) shown on vertical CNC.

### 3.4 Manufacturing scenario #4 – fused filament fabrication and CNC machining bearing housing

In this case, a part was manufactured by FFF using the NEAR NET SHAPE concept, then machined in another setup. The same deposition criteria mentioned in item 3.1 and the same machining conditions mentioned in item 3.2 were used. As a result, a longer deposition time is expected than the FFF additive manufacturing process of item 3.1 and a longer total manufacturing time due to the addition of the machining process. However, the part must present dimensional tolerance and surface finish within the required for manufacturing the bearing, fulfilling the design criteria. It is possible to present the highest cost among the other options, however, being flexible and with dimensional and finishing guarantee, as well as the lowest manufacturing cost among the 4 scenarios.

## 4. MANUFACTURING SCENARIOS RESULTS AND DISCUSSIONS

Table 4 presents the results of deposition times, machining, masses and total and partial costs that will be used in the further discussions. These values were collected during each step of the manufacturing process for the 4 scenarios.

Table 4 - Results of deposition times, machining, material requirement (grams) and costs, total and partial.

Scenario	Deposition Time (s)	Machining Time (s)	Total time (s)	Initial Mass (g)	Final mass (g)	Material kg value (US\$)	Material value per piece (US\$)	Machine hourly rate (US\$)	Manufacturing Cost - Deposition (US\$)	Manufacturing Cost - Machining (US\$)	Total Manufacturing Cost (US\$)	Total Material + Manufacturing Cost (US\$)
1	4h20m0s	0m0s	4h20m0s	74,95	74,95	107,14	8,03	4,32	18,72	0,00	18,72	26,75
2	0m0s	19m12s	19m12s	230,00	75,55	40,80	9,38	50,00	0,00	16,00	16,00	25,38
3	9m23s	14m29s	23m52s	180,00	77,50	18,14	3,27	50,00	7,82	12,07	19,89	23,15
4	6h30m	9m31s	6h39m31s	115,00	72,67	107,14	12,32	FFF + Machining	28,08	7,93	36,01	48,33

### 4.1 Cost

In scenario 1, the part was fully printed, the cost was calculated considering the machine hour value of a Desktop FFF 3D printer and the cost of the material. For this purpose, a quote was made on the Hubs website (Hubs, 2023), inserting the same manufacturing parameters used in the project. The cost of producing the piece on the Hubs site in PLA was US\$22,56, considering a kilogram of PLA US\$21,00 according to the Creality website and the amount of material used 74,95g, the cost of PLA used was US\$3,82. Deducting the value of the material from the price of the part, we have

US\$18,74 in operating cost. Considering that the time to manufacture the part was 4,33 hours, the hourly cost of the machine is US\$4,32. The material used to manufacture the bearing housing was Brasken FL900PP-CF filament, which costs US\$107,14 per kilo according to the Xtellar site (Xtellar, 2023). The cost of filament used to manufacture the bearing was \$8,03 per piece. Adding material and manufacturing costs comes to a total of \$26,75.

In scenario 2, the part was manufactured fully machined, starting from a 230 g raw part. The value of the material for this process was extracted from the website of the manufacturer Curbellplastics (Curbell Plastics, 2023), which sells PP-CF sheets, with a cost of US\$77,87 per kilogram. The material cost for part 2 was \$9,38 per part. The cost of machining was calculated considering the hourly machine price commercially practiced in Brazil in 2023, being the amount of R\$250,00 machine hour, equivalent to approximately US\$50,00. Machining time for scenario 2 was 19 m 12 s, so the machining cost of the part was US\$16,00 and its final mass was 75,55 g. The total manufacturing cost was US\$25,38.

In scenario 3, the part was manufactured using the BAAM process, the machine hour value was considered the same as for part 2, as we used the same equipment for hybrid manufacturing (deposition and machining). The first fabrication step, high flow deposition, lasted 9 m 23 s, had a fabrication cost of US\$7,82 and deposited 180 g of material at a cost of US\$3,27. The second stage, machining, lasted 14 m 29 s and its manufacturing cost was US\$12,07. The total cost for scenario 3 was US\$23,15, a cost reduction of 9,63%. This result was expected due to the lower cost of the pellet and the lower material cost using the NEAR NET SHAPE concept. When analyzing only the cost of the material for the manufacture of the four parts, we will see that the BAAM presents a reduction between 2,4 to 3,7 times in the cost of raw materials.

In scenario 4, the part was manufactured by printing the preform on the 3D printer and finishing the part by machining in the ROMI machining center. The preform deposition time was 6 h 30 m, at a manufacturing cost of US\$28,08, and the part weighed 115 g, at a cost of US\$12,32. The machining of the part took 9 m 31 s, at a production cost of US\$7,93. The total cost of production US\$48,33, the highest among all processes.

## 4.2 Quality

The quality criterion adopted was based on the use of the part, for this case study, it is necessary to assemble a bearing in the bearing housing seat. To carry out this assembly, the manufacturer's catalog was consulted and the appropriate values were established for the housing seats in accordance with tolerance class M6. According to this criterion, the dimensional variation of the seat must be between 61,995 and 61,976mm, that is, tolerance between  $-0,004\mu\text{m}$  and  $-0,024\mu\text{m}$ . Parts 2, 3 and 4, which underwent a machining process, ensured this quality. Table 5 shows the average of a cycle of five measurements taken with a Mitutoyo Internal Micrometer. The only rejected part was part 1 manufactured entirely by printing, as it was not possible to assemble the bearing as shown in Figure 7, which was already expected due to the intrinsic tolerances of the manufacturing process by 3D printing.

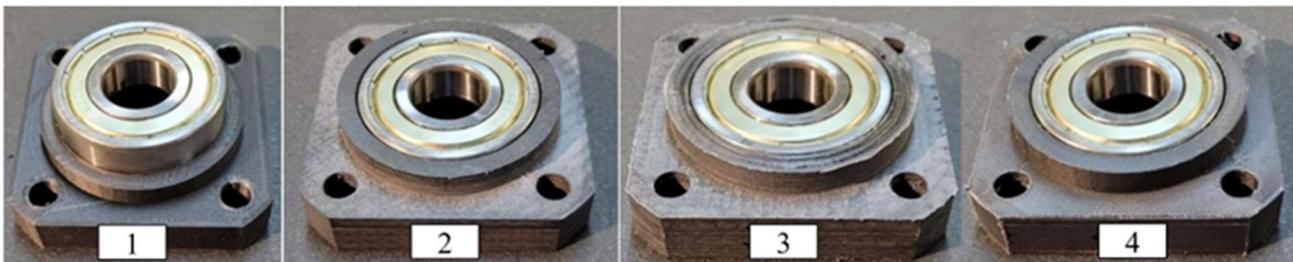


Figure 7 - Assembly of bearings in the four housings.

Another criterion adopted for quality measurement was the surface roughness of the bearing seat, for which a Mitutoyo SJ301 roughness meter was used. Parts 2, 3 and 4, which underwent the machining process, had a roughness class below N8, sufficient for the process. Part 1, printed, presented roughness class N12, this characteristic is due to the height of the layer used in the deposition process, which was 0,4mm, if the value were lower, the surface roughness would be reduced, however, the time of manufacturing would increase, impacting the final cost of the part.

Table 5 - Measurement values for the internal diameter and roughness of the parts.

	Measurement values (mm)						Roughness	
	1	2	3	4	5	Average	Ra(μm)	Rz(μm)
scenario #1	61,630	61,665	61,705	61,673	61,665	<b>61,668</b>	25,58	124,10
scenario #2	61,985	61,995	61,980	61,990	61,975	<b>61,985</b>	1,14	7,62
scenario #3	61,995	61,975	61,975	61,995	61,995	<b>61,987</b>	2,11	11,57
scenario #4	61,985	61,990	61,990	61,975	61,980	<b>61,984</b>	1,37	11,14

### 4.3 Productivity

Comparing all scenarios, cases 1 and 4 had a very high manufacturing time compared to 2 and 3, as shown in table 4. Machining manufacturing has an advantage over the other processes, with manufacturing time being 19 m 12 s and the second best time was performed by BAAM, with 2 3m 52 s, a difference of 24,27% more in production time. From this aspect, we can conclude that machining is the most productive process, as expected, due to the performance of only a single process, with high production equipment.

### 4.4 Flexibility

Parts manufactured by additive manufacturing have larger flexibility, as they are not limited to the geometry of the part to be produced. It has a shorter setup time, as the part is manufactured directly on the printer's table, with no need for any other adjustment. When manufactured exclusively by the machining process, it is necessary to preset all the tools and fixtures that will be used for that application. If there is a change in the part's geometry, it will be necessary to change the devices, as well as the presetting of the new tools. It will also be necessary to have a blank to manufacture the desired part, which will come from other processes such as cutting or pre-machining. Depending on the diversity of parts produced, it may still be necessary to purchase sheets of different thicknesses, blanks of different diameters or custom castings. These facts reduce flexibility and increase production costs in machining. For BAAM, it is necessary to preset the tools that will be used in machining, the head deposition and the installation of the vacuum table on the machine's bus, where the deposition of the parts will take place. BAAM uses the parts deposition reference to carry out the machining, streamlining the manufacturing process, not requiring fixtures according to the part's geometry. By using pellets, the geometry, shape and dimensions of the parts that will be produced are not a limiting factor for this process. The 3D printing process has larger flexibility due to ease of manufacture, while BAAM has good flexibility due to deposition and also adds the advantages of the machining process. In machining, due to the need to adjust each change in the geometry of the part, it has limited flexibility.

## 5. CONCLUSIONS

The purpose of this study was to produce a commercial part, in this case, a bearing housing, through 3 combinations of manufacturing processes, namely, fused filament manufacturing (FFF), large area additive manufacturing (BAAM) and CNC machining. They were divided into 4 different scenarios in order to study the different possible manufacturing combinations, scenario #1 - Fused Filament Fabrication bearing housing, scenario #2 – CNC machined bearing housing, scenario #3 – Hybrid Additive Manufacturing bearing housing (BAAM + CNC machining), scenario #4 – Fused Filament Fabrication and CNC machining bearing housing. By carrying out the different scenarios, it was possible to verify the characteristics of each one in terms of cost, quality, productivity and flexibility presented in Table 6.

Table 6 - Comparison between the four manufacturing scenarios.

	Cost	Quality	Productivity	Flexibility
Scenario #1	LOW	LOW	LOW	HIGH
Scenario #2	LOW	HIGH	HIGH	LOW
Scenario #3	LOW	HIGH	HIGH	HIGH
Scenario #4	HIGH	HIGH	LOW	HIGH

Thus, it is possible to compare and conclude that BAAM has a low production cost, as it had the lowest manufacturing cost among all possible ones, high quality, reaching the required dimensional tolerancing and surface finishing. It also showed high productivity, obtaining the second-best production time and high flexibility, being able to manufacture parts with the most varied profiles without needing to change the material and/or fastening devices. With this it can be concluded that YES, the hybrid additive manufacturing is the best option when we compare cost, quality, productivity and flexibility.

## 6. ACKNOWLEDGEMENTS

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