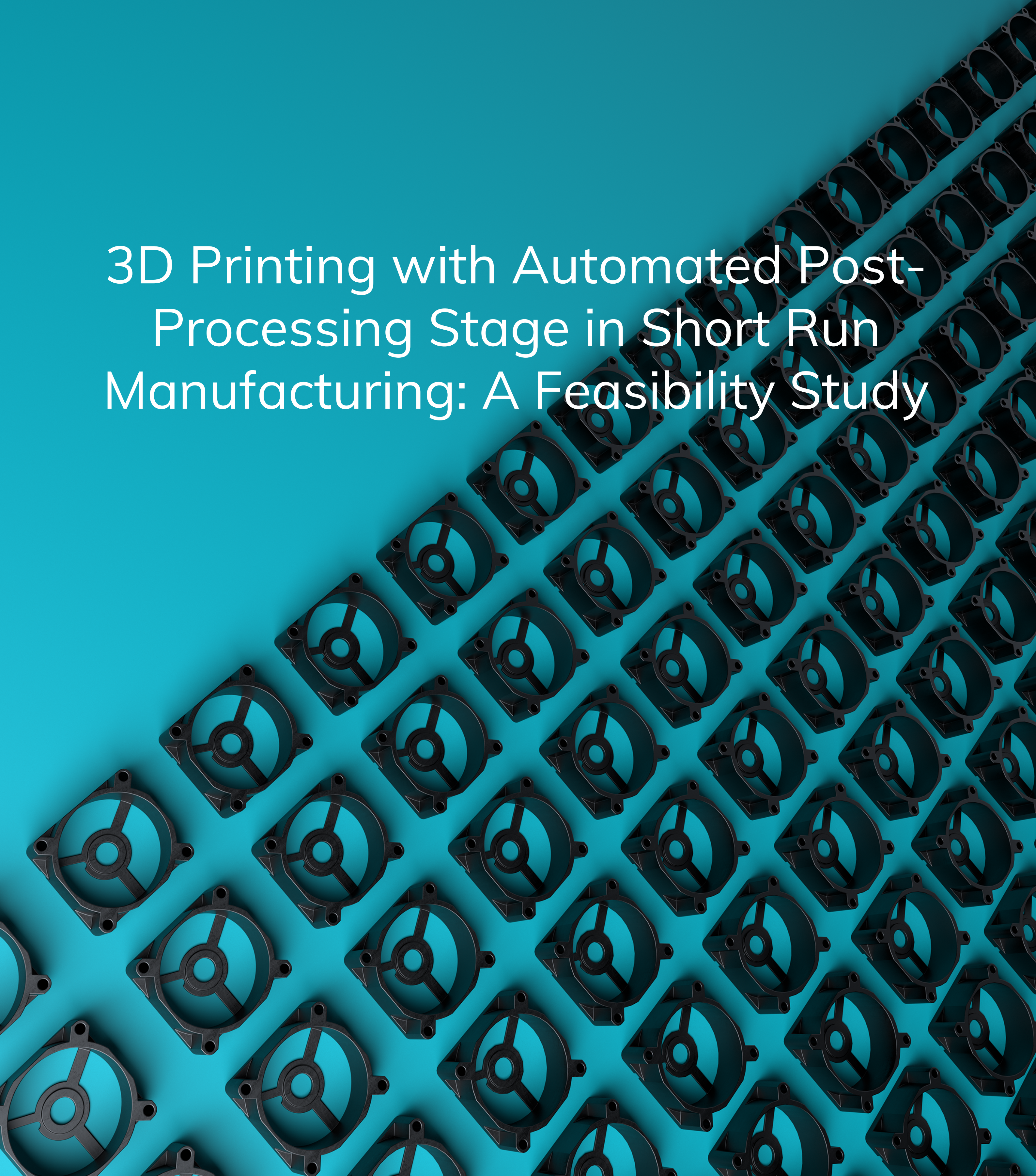
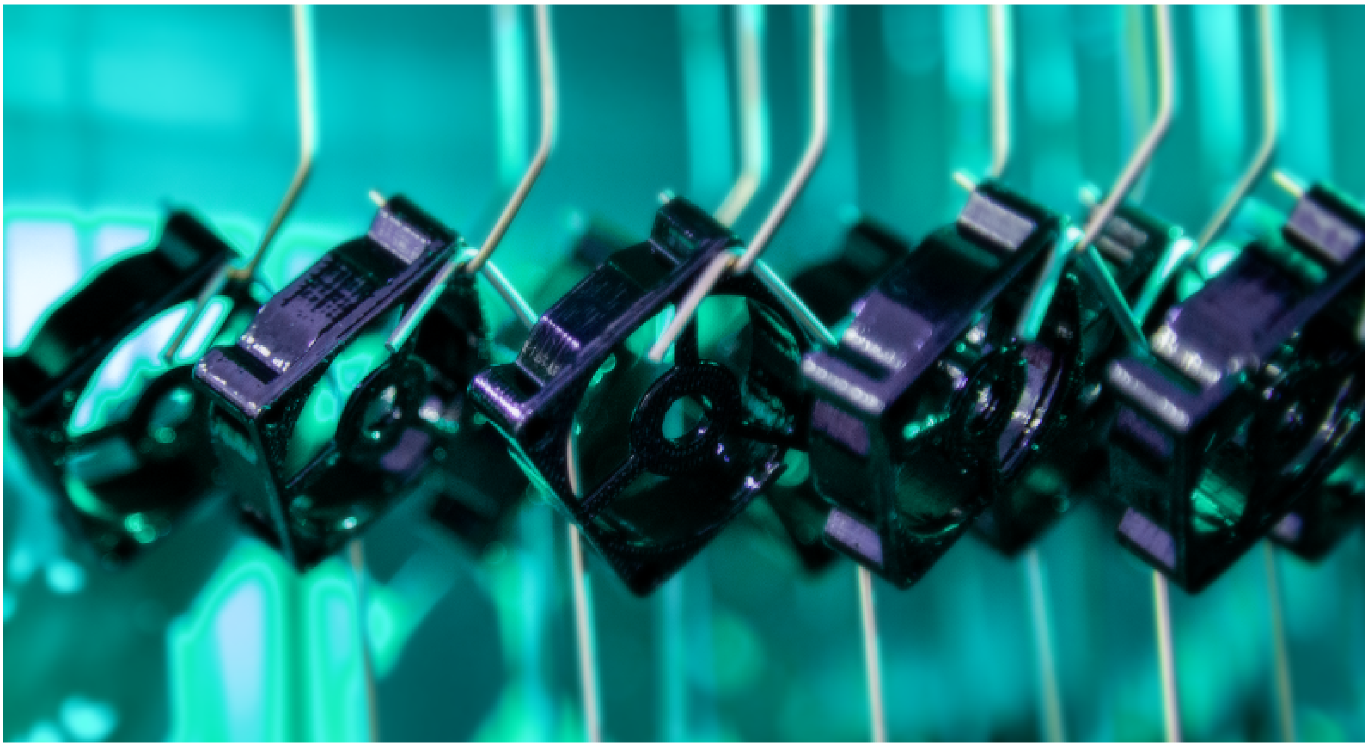
zortrax

3D Printing with Automated Post-Processing Stage in Short Run Manufacturing: A Feasibility Study



Abstract

3D printing farms are deemed economically feasible for short-run manufacturing. It has been demonstrated that 3D printing is the most cost-efficient manufacturing process for the series of 500 to roughly 5000 units, depending on the size and complexity of the product. But it has rarely been considered as a viable alternative to traditional manufacturing due to inferior surface quality. Further post-processing stage is needed before a 3D printed model can achieve smooth surfaces comparable to its mass-produced counterpart. The amount of manual labor necessary to get this done properly is usually cost-prohibitive.



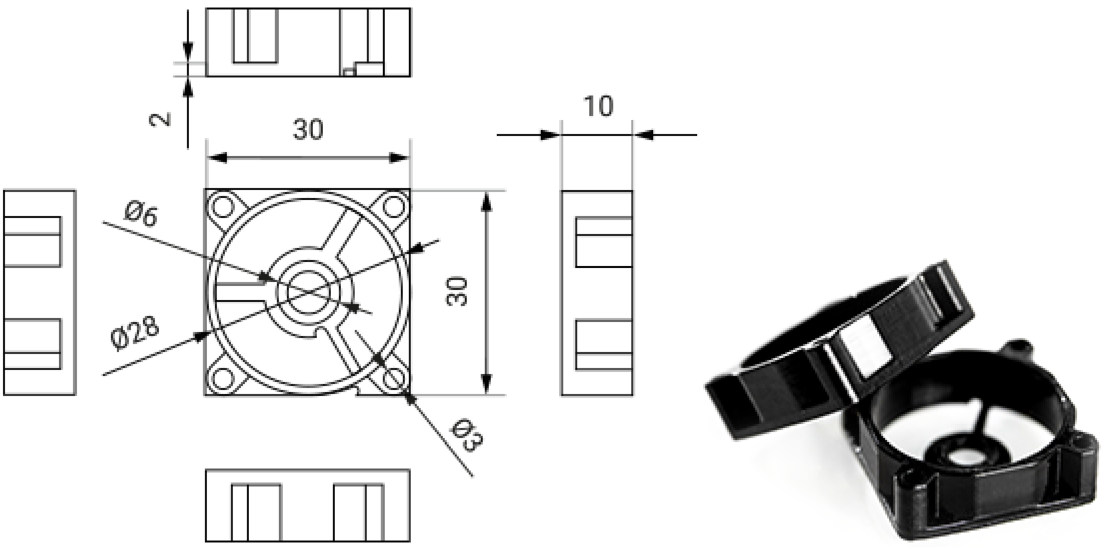
But the recently introduced automated post-processing technologies like Zortrax SVS (Smart Vapor Smoothing) justify revisiting the issue. In this study, we have analyzed the performance of FDM/FFF 3D printing with an automatic post-processing stage in manufacturing a short series of 500 computer fan covers.

Multiple costs simulations have been made for numerous business scenarios to account for variables like product's complexity and a length of the manufacturing period. To put those findings in perspective, we have analyzed how injection molding technology performs under the same conditions.

Introduction

Short run manufacturing is usually used in two scenarios. The first one is bridging the gap between prototyping and mass manufacturing stages in the product development cycle. Having the first 500 units 3D printed mitigates allows cost-free design changes and makes market validation possible before going into full-scale production. The second scenario is the on-demand manufacturing of infrequently ordered spare parts. Suppliers usually stop offering them at some point because of excessive costs of storage. This move, in turn, forces the customers to either store those parts on their own or turn to third-party manufacturers.

A computer fan cover has been chosen for this study because it makes sense in both scenarios mentioned above. Prior to mass production phase, 500 fans can be used to test if the design provides efficient cooling. A fan cover is also likely to qualify as an infrequently ordered spare part. ABS (acrylonitrile butadiene styrene) was the material of choice for the computer fan covers as this is what such parts are almost always made of in real-life conditions.



A computer fan cover design used in the study

Results

Manufacturing 500 Units of a Single-Element Product

In manufacturing a single series of 500 single-element computer fan covers, the injection molding ended up with a slight edge over the 3D printing with an automated post-processing stage in terms of the amount of necessary investment and price per unit. Going for the 3D printing option, in turn, led to a shorter time-to-market and ownership of more versatile production assets that could be used in future projects. The exact costs breakdown can be found in the table below.

Manufacturing process	Cost per unit	Investment	Lead time	Ownership
Injection molding	10 USD/ 8.87 EUR	5002.39 USD/ 4433.29 EUR	15 weeks	One mold
3D printing with automated postprocessing	16.11 USD/ 14.28 EUR	8055.77 USD/ 7139.30 EUR	6 weeks	The M200 Plus 3D printer and Apoller SVS device

Costs of producing 500 single-element products by 3D printing and injection molding

A superficial analysis of those findings may lead to believe that the main difference between 3D printing and injection molding in short-run manufacturing comes down to paying more for cutting the time-to-market by half.

We have found it to be valid under two conditions. First, the product is made of a single element. Second, manufacturing 500 units of the product is a one-off with no further short series production scheduled.

Manufacturing 500 Units of a Multi-Element Product

To find out how an increase in the product’s complexity would affect the overall feasibility of the two manufacturing processes in question, we have calculated how injection molding and 3D printing with an automated post-processing stage would perform in manufacturing products consisting of two, three, and four elements.

We have assumed that each of the 500 units of a two-element product is made of two parts of similar size and complexity. We have also assumed that two single cavity molds are necessary for injection molding of two separate parts. The cost breakdown of manufacturing a two-element product is summed up in the table below.

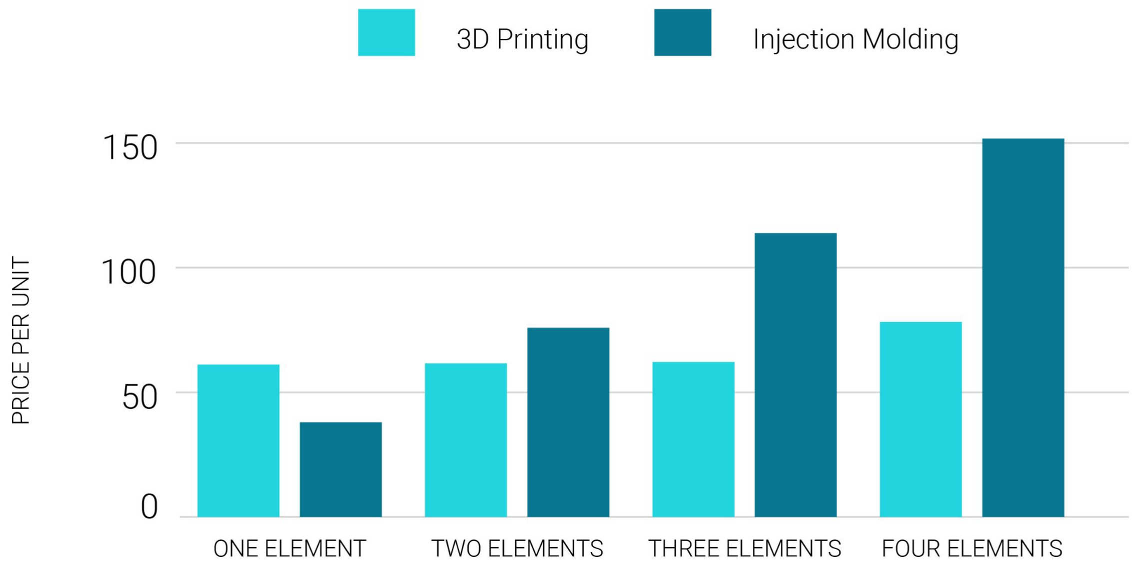
Manufacturing process	Cost per unit	Investment	Lead time	Ownership
Injection molding	20.01 USD/ 17.73 EUR	10004.78 USD/ 8866.58 EUR	15 weeks	Two molds
3D printing with automated postprocessing	16.11 USD/ 14.28 EUR	8124.33 USD/ 7200.06 EUR	12 weeks	The M200 Plus 3D printer and Apoller SVS device

Costs of producing 500 two-element products by 3D printing and injection molding

In manufacturing a slightly more complex product (two parts instead of one), the injection molding proved to be less feasible than 3D printing with automated post-processing. To see how this upward trend for the feasibility of 3D printing would behave if the complexity of the product were increased even further, we have analyzed the cost per unit for products consisting of three and four elements as well. Our findings are shown in the chart below.

Product’s complexity

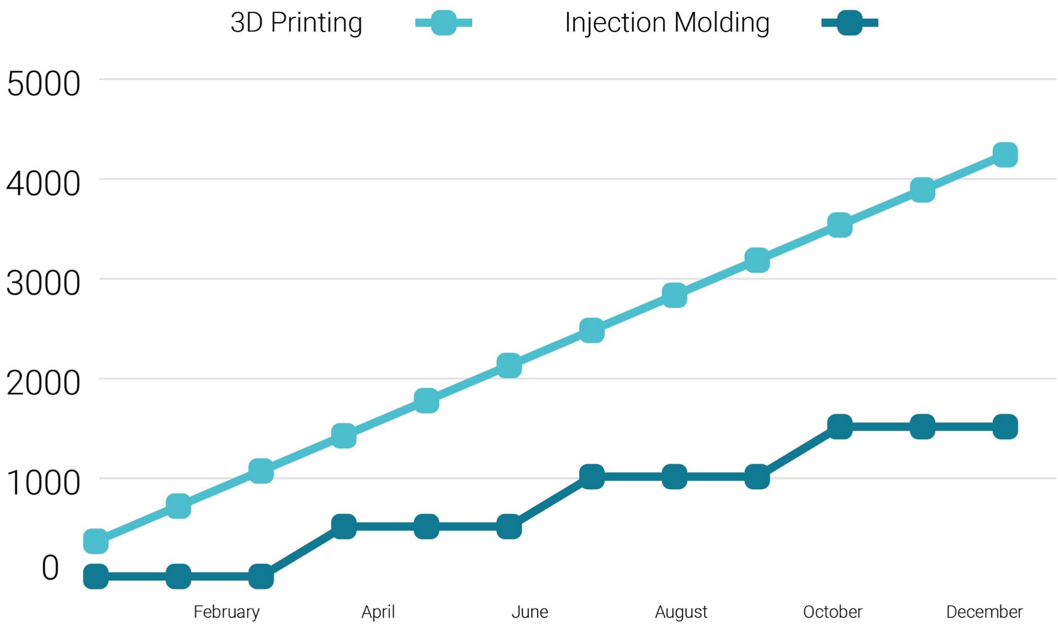
The extent to which increasing the product’s complexity affected the price per unit has been found to be negligible in the 3D printing option. A more noticeable increase was present only in the case of a 4-element product. This was due to including an additional 3D printer in the overall investment. We have found an additional 3D printer necessary to keep the 12 weeks lead time. In the injection molding technology, increasing complexity resulted in a steep rise in the price per unit. The reason behind this is that elements with different designs could be made on the same 3D printing equipment at no additional cost, while making them with injection molding required ordering an additional mold for each additional part. The discrepancy would be tilted back in favor of injection molding if we were to manufacture higher numbers of the exact same set of parts in the future. But the whole point of short run production is that after having made a limited series of one product, we need to move on to making a limited series of another.



Price per unit vs product's complexity

Costs of Continuous Short Run Manufacturing

In a business scenario where making 500 units of a product was not a one-off but was being done continuously over long periods, 3D printing with an automated post-processing stage led to costs per unit that were significantly lower than in injection molding. Moreover, the 3D printing option yielded a much higher yearly manufacturing output. The number of units possible to produce per year is shown in the chart below.



Yearly output in short run production

A somewhat counterintuitive discrepancy in the yearly manufacturing output results from significantly longer lead times in the injection molding option. Because short run productionalmost always happens on demand, we have assumed the manufacturer did not have prior knowledge as to the specific designs of products that are going to be manufactured. It was therefore impossible to have all the necessary molds ordered in advance. The table below sums up the costs and lead times per product in continuous manufacturing of succeeding series of 500 units of different products over one year.

Manufacturing process	Cost per unit	Investment	Lead time	Yearly output	Ownership
Injection molding	10 USD/ 8.87 EUR	15007.17 USD/ 13299.87 EUR	15 weeks/ product	1500 units	Three molds
3D printing with automated postprocessing	1.97 USD/ 1.75 EUR	8583.70 USD/ 7607.17 EUR	6 weeks/ product	4350 units	The M200 Plus 3D printer and Apoller SVS device

Costs of continuous short-run production of single-element products over a year

To show how this trend extends over a longer time, we have made the cost analysis for the five years long short run production. Our finding have been as follows:

Manufacturing process	Cost per unit	Investment	Lead time	Yearly output	Ownership
Injection molding	10 USD/ 8.87 EUR	85040.61 USD/ 75365.91 EUR	15 weeks/ product	8500 units	Seventeen molds
3D printing with automated postprocessing	0.52 USD/ 0.45 EUR	10958.05 USD/ 9711.40 EUR	6 weeks/ product	21666 units	The M200 Plus 3D printer and Apoller SVS device

Costs of continuous short-run production os single-element products over 5 years

We have found that price per unit in continuous short run production decreases over time in 3D printing option and remains constant in injection molding. Again, this is because only one design of part can be manufactured per mold.

In the last step, we have calculated to what extent overlapping those two factors affect the feasibility of short-run production in two processes under consideration. Here are our findings for a scenario involving five years long continuous short-run production of 4-element products in a series of 500 units per product.

Manufacturing process	Cost per unit	Investment	Lead time	Yearly output	Ownership
Injection molding	39.87 USD/ 35.47 EUR	338872.49 USD/ 301463.65 EUR	15 weeks/ product	8500 units	68 molds
3D printing with automated postprocessing	1.50 USD/ 1.33 EUR	15740.72 USD/ 14003.07 EUR	12 weeks/ product	10500 units	Two M200 Plus 3D printers and an Apoller SVS device

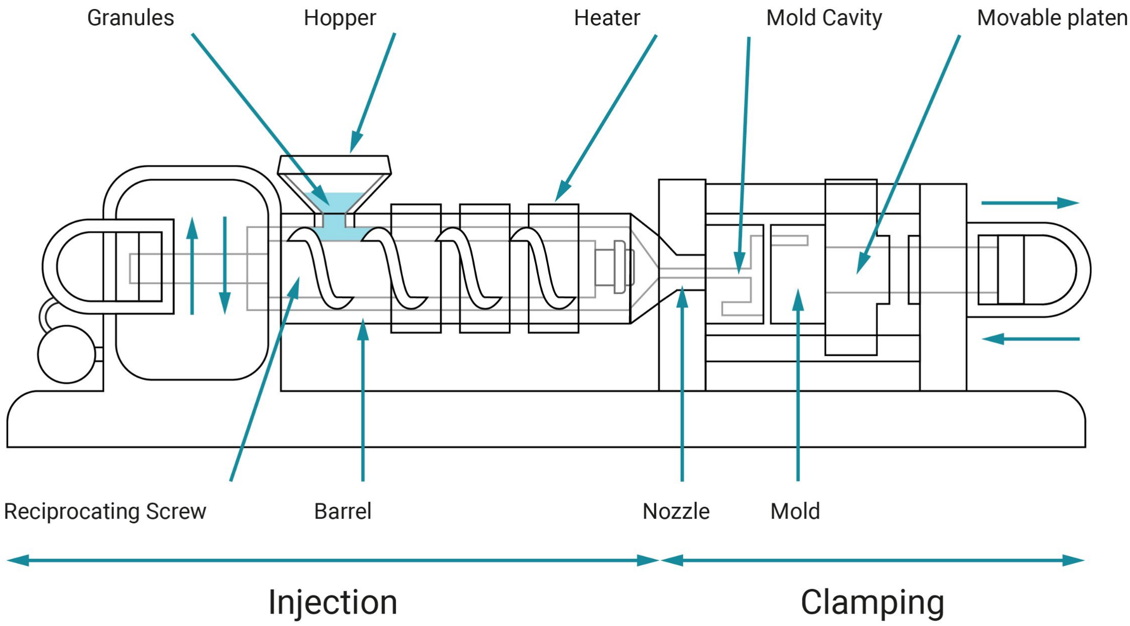
Costs of continuous short-run production of 4-element products over 5 years

We have added a second M200 Plus 3D printer in this scenario to keep lead times comparable with the injection molding option. With two 3D printers producing 4-element products for five years, the yearly manufacturing output turned out to be closer to injection molding than it was in the case of a single-element product. The most striking discrepancy emerged in the price per unit. In the 3D printing option, adding three more elements to the product resulted in a 1 USD/ 0.89 EUR increase in price per unit. In the injection molding, the price increase by a staggering 29.90 USD/ 26.60 EUR.

Methods

Injection Molding

An injection molding is a technology commonly used in mass production. Parts are manufactured by injecting molten material into a mold, a hollow block where the material hardens adopting its shape.



Injection Molding Machine

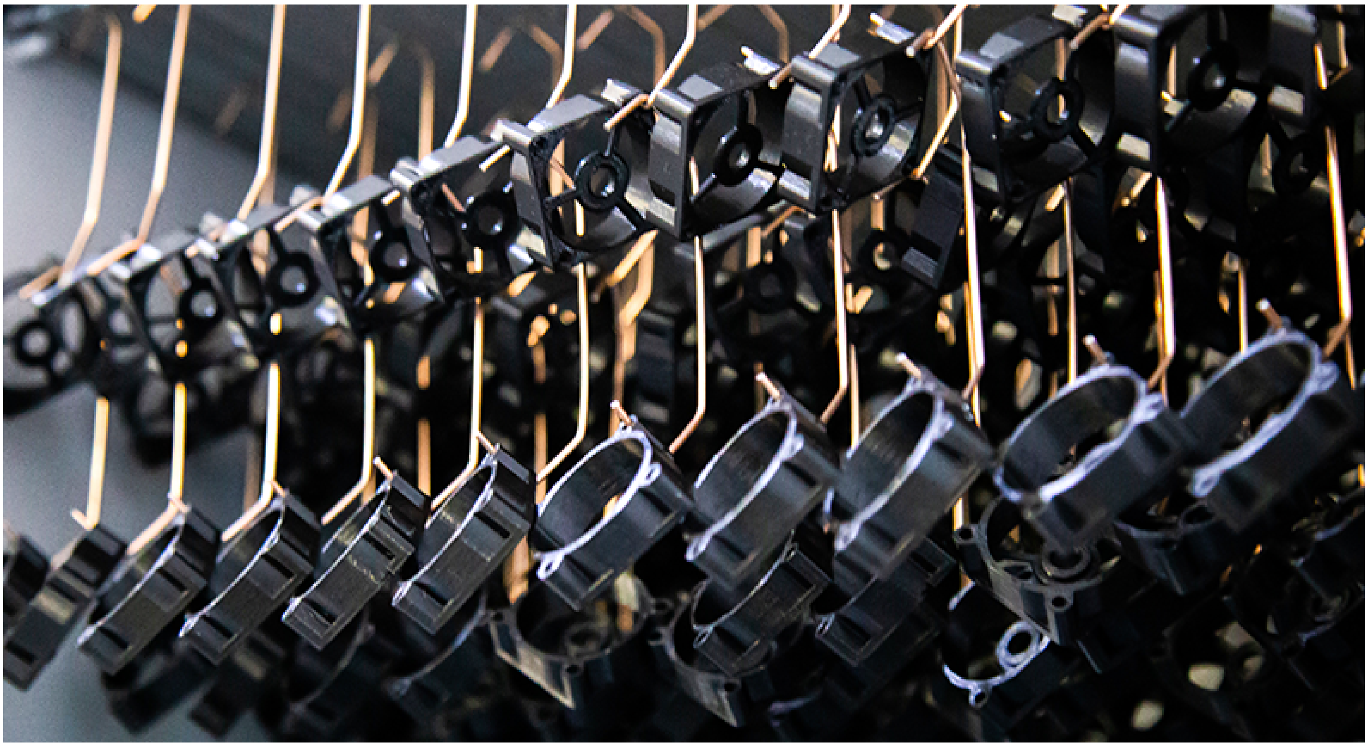
A separate mold has to be made for each part. The downside is the high cost of the mold that needs to be paid upfront. The upside is that a mold is reusable, so the price per unit drops with the rising scale of production. To estimate the costs of injection molding in short-run manufacturing, we have asked for a quote on making 500 computer fan covers of the design used in the study. In the table below is the detailed breakdown of the offer we have received.

Mold	4562.01 USD/ 4043.01 EUR
Material	Black ABS
Minimum Order Quantity (MOQ)	1000
Surface Finish	Glossy
Price per unit	0.44 USD/ 0.39 EUR
Total	4983.42 USD/ 4433.29 EUR

Summary of the injection molding offer

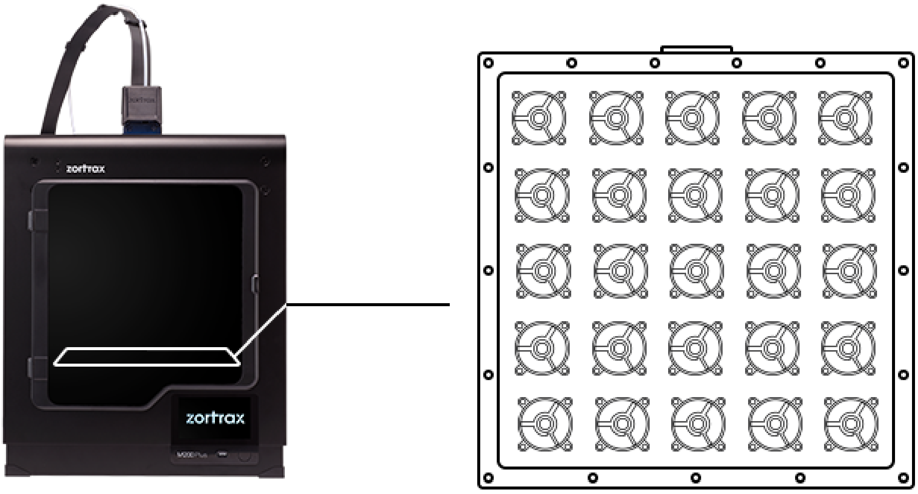
The manufacturer who made the offer left us with two possibilities. We could have the mold made in Guangdong, Shenzhen, China, and transported to the factory in the European Union either by sea or by train. The former had the shipping costs included in the price of the mold but would take a total of 15 weeks to have the production line up and running. The latter could cut this time down to 12 weeks, but we would have to cover the costs of shipping by train on our own.

The price per unit would, therefore, end up at 10 USD/ 8.87 EUR with the first fan covers available after at least 105 days. The more expensive train option has not been considered. Having invested a total of 4983.42 USD/ 4433.29 EUR, we would end up as owners of the mold and be free to order further fan covers for the agreed upon 0.44 USD/ 0.39 EUR apiece. The costs of storage for the excessive 500 fan covers have not been included. Still, it is worth mentioning we have been unable to negotiate the MOQ down to 500 units.



3D Printing with Automated Post-Processing

To estimate the feasibility of manufacturing 500 fan covers on a 3D printer working with an automated post-processing device, we have been using the following setup. First, the parts have been printed on the Zortrax M200 Plus LPD 3D printer.

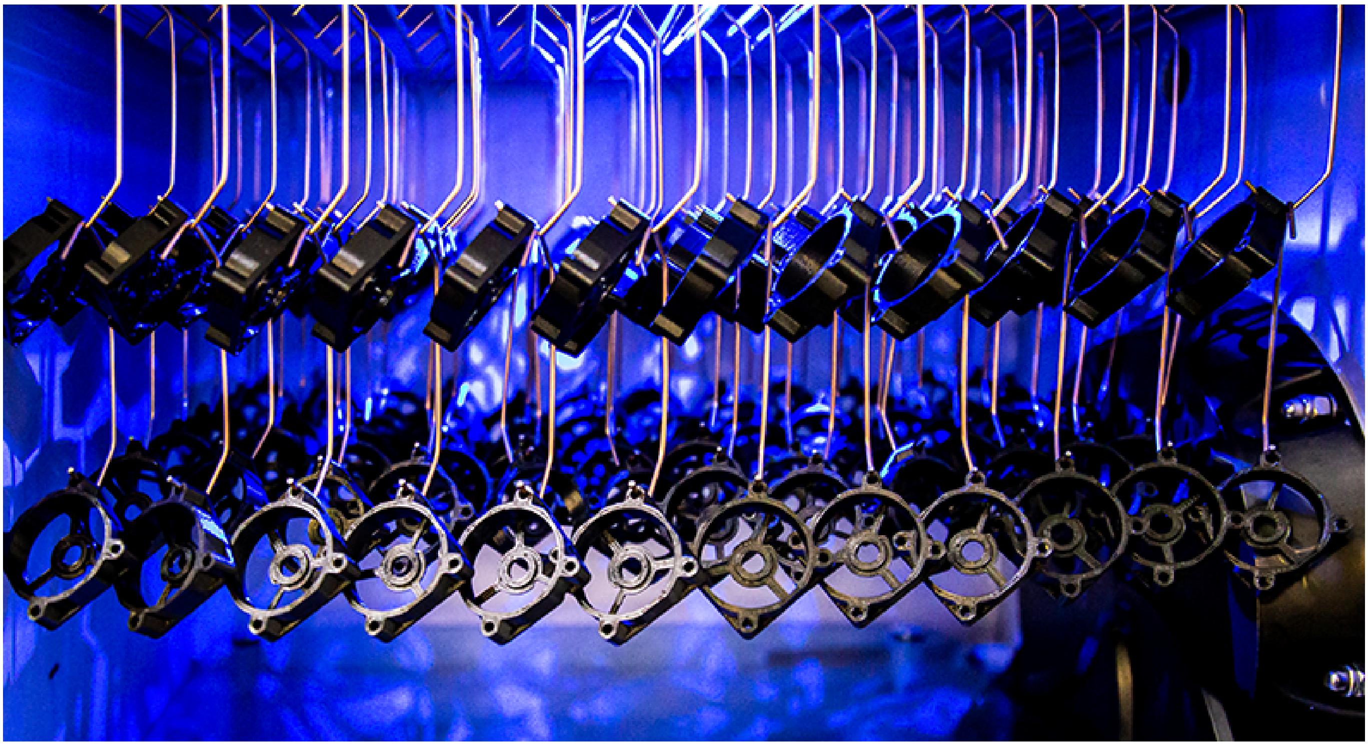


Then we have proceeded to test to what extent using a larger M300 Plus machine would affect the overall cost. In both cases, fan covers have been made with Z-ULTRAT, a durable ABS-based filament suitable for end-use products. Zortrax Apoller SVS device has been used as an automated post-processing tool to achieve smooth, glossy surfaces. The time and cost of 3D printing are broken down in the table below.

3D printer	Parts per cycle	Printing time	Filament usage	Filament cost
M200 Plus	25	17h	86 g	3.42 USD/ 3.04 EUR
M300 Plus	64	43h	216 g	7.62 USD/ 6.78 EUR

Costs and time of 3D printing computer fan covers on the M200 Plus and M300 Plus 3D printers

The total time required to make a series of 500 fan covers with one M200 Plus 3D printer working for 8 hours a day was slightly over six weeks.

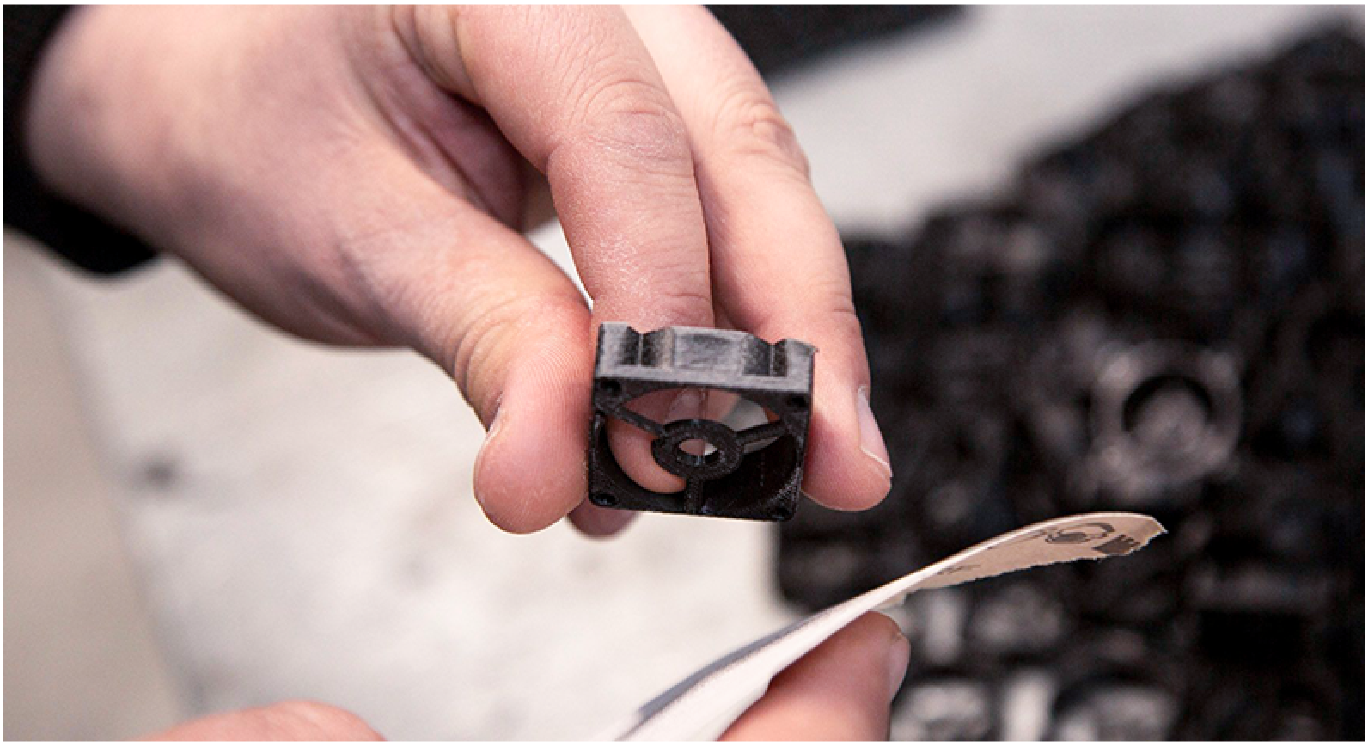


Under the same conditions, the M300 Plus completed the task in a bit under six weeks. The total cost of filament used by each of the printers amounted to 65.67 USD/ 58.42 EUR. Having the models done, we moved on to the post-processing stage.

Manual post-processing techniques to make the fan covers' surfaces smooth and glossy involved sanding and painting. Sanding of 500 parts took two full days. Painting them with a spray paint took over 6h with further 6h necessary for drying out. Overall, manual post-processing totaled 54 hours of labor.

The costs of human labor are difficult to estimate as wages in different parts of the world may vary significantly. Still, we find it safe to assume they would prove more and more prohibitive with the growing scale of production.

Automated vapor smoothing is an alternative technique to achieve smooth glossy surfaces. Zortrax Apoller SVS device we have used for this study could accommodate 256 fan covers in its smoothing chamber. The entire run of 500 fan covers has been post-processed in two 3-hour-long smoothing cycles. The total cost of the process did not exceed 2.63 USD/ 2.34 EUR.



The overall cost breakdown can be found in the table below. Seeking rational savings, we have opted to go with the smaller M200 Plus 3D printer, as in this particular application its performance is on par with the larger M300 Plus machine.

Zortrax M200 Plus	2046.43 USD/ 1820,52 EUR
Zortrax Apoller	5910.49 USD/ 5258.02 EUR
Filament	65.67 USD/ 58.42 EUR
Acetone	2.63 USD/ 2.34 EUR
Total	8025.22 USD/ 7139.30 EUR

Costs of 3D printing and automated post-processing of 500 computer fan covers

The cost per unit totaled 15.05 USD/ 14.28 EUR. We have had all 500 fan covers made in 6 weeks. There was no need to change the design, and we ended up as owners of both the M200 Plus 3D printer and the Apoller SVS device which could be used in future projects.

Conclusions

In this study, we have examined two candidate manufacturing processes for producing a short run of 500 computer fan covers. We have found that the injection molding technology has a slight edge over the 3D printing with automated post-processing stage in a one-off production of 500 single-element fan covers. This edge begins to vanish, though, with the growing complexity of the product. Addition of just one part to the design results in 3D printing getting a little ahead of injection molding in terms of feasibility, adding three more elements resulted in 3D printing gettingway more price-competitive.

But the flexibility of 3D printing starts to make the real difference in continuous short-run manufacturing. Over a year, it offered the manufacturing output nearly three times higher than the injection molding. The cost per unit was over five times lower while the initial investment required to launch the production stood at around 60% of what was needed for setting up traditional manufacturing lines. Over five years, the gap in price per unit significantly widened to become over 19 times lower at the end of year 5.

Increasing a product's complexity in parallel with extending the period of short-run manufacturing has two demonstrable consequences. First, the manufacturing output starts to equalize between the two technologies. Second, the price per unit rose by 1 USD/ 0.89 EUR in the 3D printing option and by as much as 29.90 USD/ 26.60 EUR in the injection molding option. Because 3D printers working with automated post-processing devices do not need retooling each time a product's design is changed, those savings have been demonstrated to grow over time in short-run manufacturing.

Zortrax S.A., entered in the Register of Entrepreneurs of the National Court Register kept by the District Court in Olsztyn, VIII Commercial Division of the National Court Register, under KRS number 0000564079, with a share capital of PLN 7 462 500 paid in full.