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Technical and financial feasibility assessment of producing an impeller sand mould by three-dimensional printing using a Voxeljet VX 1000 machine

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Abstract. Impeller castings are some of the most critical components used in engineering applications with complex designs. The high-quality production of their sand mould is essential to ensure optimal casting properties. Three-dimensional printing is an appropriate modern technology that can manufacture such moulds at a shorter production lead time than traditional methods. This paper assesses the technical and economic feasibility of producing the impeller sand mould for casting a mining impeller pump using a Voxeljet VX1000 printer available locally. The methodology includes the use of casting simulation and the application of the financial payback period method. This paper provides a practical case study of the theoretical assessment of rapid sand casting projects. The payback period showed the rapid sand casting process for printing impeller sand mould using the VX1000 printer is feasible for adoption by the local foundry industry as the initial investment is recovered within the 5 years of the projected cash flows.

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1 Introduction

An impeller is a cast metal component made up of vanes from an open inlet at the centre that rotates within a centrifugal pump design [1]. Due to its application in transferring energy from the pump design motor to the fluid, its performance during application is very significant and critical [2]. These cast metal components are usually very complex in design, and high-quality sand moulds used to produce their castings are essential in ensuring proper applications and performance. The castings can be produced from different alloys, including stainless steel, carbon steel, iron, bronze or plastics and can be found in various industries, including the mining, chemical, oil and gas industries [3].

Traditional manufacturing methods are currently used to fabricate sand moulds and cores for impeller castings in South Africa, which require tooling-like patterns to manufacture them. In a normal foundry, it can take from 3 to 8 weeks to produce a specific casting [4] from the design of the pattern to the quality assessment of the final casting. Sometimes these patterns degrade over time, which can affect the original dimensions.

Due to their advantages, which outweigh those of traditional manufacturing, additive manufacturing (AM) technologies can be used to manufacture impeller moulds and cores. These advantages include fabricating parts with minimal waste, high-dimensional accuracy, less need for post-processing, and the ability to create very complex and intricate geometries and economically [5]. AM methods use computer-aided design (CAD) to design a part in a few hours without tooling, which saves both time and money [6].

One of the AM three-dimensional printing (3DP) technologies, namely the binder jetting process, can now be used to fabricate the sand mould for impeller castings without pattern making [7]. This process is also referred to as rapid sand casting as it is faster and more efficient than traditional manufacturing [8]. This is achieved by modelling a component using data from CAD and applying the layer-by-layer principle [9], which facilitates the introduction of new components with a shorter production lead time [10]. It also allows the production of tangible models with enhanced quality more quickly and with less tooling compared to traditional methods of manufacturing, which minimise waste material. Other advantages of AM over traditional manufacturing methods include reduced raw material required to manufacture a part, reduced power consumption, and reduced waste and pollution [11] compared to conventional sand moulding processes. These benefits stem from the fact that sand mould design is generally more straightforward because draft angles are not required. In addition, the AM processes are quieter and produce less fines and waste sand because of the high recyclability potential of excess sand used during printing. Furthermore, AM technologies can produce very complex parts more easily than traditional manufacturing processes [11].

Despite the advantages of additive manufacturing (AM), there exists a drawback commonly referred to as the "stair-step" effect. A phenomenon related to 3D printing which occurs when layering patterns become visible on the surface of a printed object, creating the visual impression of a staircase-like texture [12]. This effect cannot be eliminated by a certain printing orientation but by binder concentration, where the binder saturation is controlled in the individual voxel volume either by over filling or underfilling them through variations in droplet size and the application of dithering and grey scaling [13]. This setback can also be eliminated by post processing or evaluation of certain printing parameters including the layer thickness, the build direction or scan strategies, ongoing research efforts are focused on uncovering proactive measures or strategies to get rid of the stair-step effect before it even shows in 3D printed objects [14]. Figure 1 compares the production costs of designing, manufacturing and pouring using traditional manufacturing methods to those using AM methods [15].

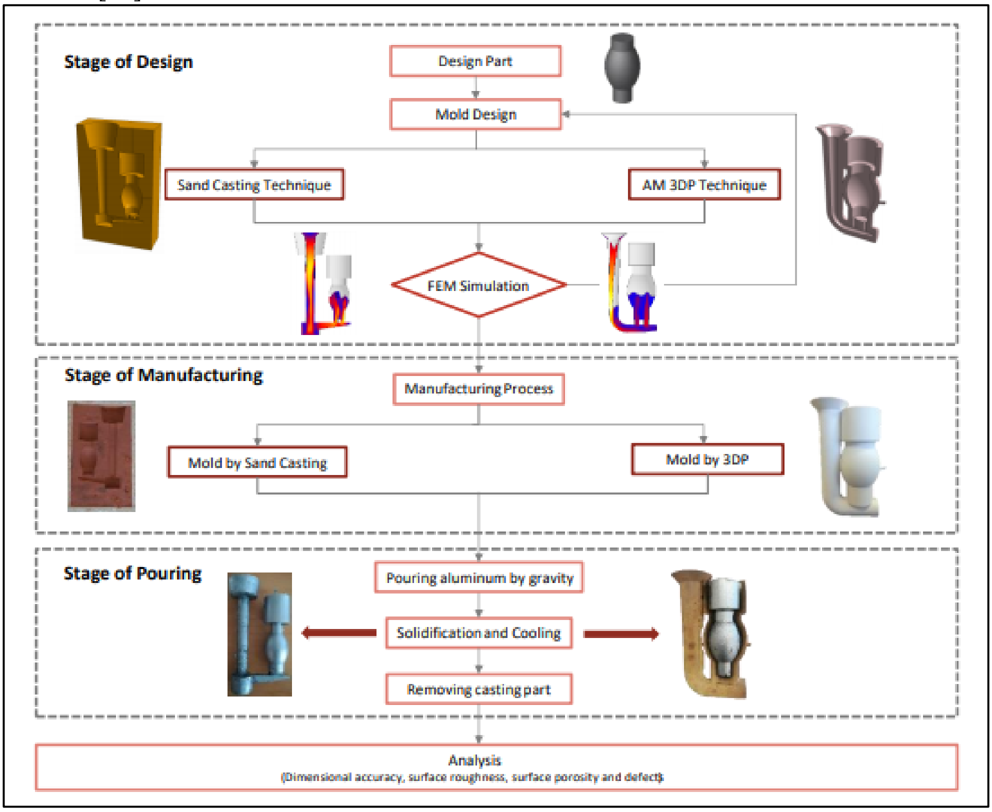

Fig. 1. Comparison between traditional sand casting and the 3D methods [15].

Rapid sand-casting technologies have shown growth since the evolution of AM processes [16], but have still to be fully adopted by the local foundry industry. This delay is due to insufficient knowledge of the economic feasibility of using AM processes for sand mould and core production. Because of this delay, rapid sand casting is the subject of ongoing research. AM technology has been available in SA for more than 25 years with the Vaal University of Technology (VUT), Central University of Technology (CUT) and University of Johannesburg (UJ) being the only institutions with rapid sand-casting machines used for research purposes [17], innovation and mould making for the local foundry industry.

Previous research has explored the cost comparisons between traditional methods and AM processes in various studies. This involves evaluating the costs of AM by contrasting them with those of traditional manufacturing processes and identifying the resources employed during different stages of manufacturing [18]. [19] measured the economy aspect of AM technology which included the cost and benefits of using this technology, by comparing AM processes to traditional processes to determine under what circumstances is AM cost effective. [20] conducted a comprehensive evaluation of the cost structure associated with AM technology. This evaluation encompassed preliminary, technical, and economic assessments, along with the calculation of product costs, which can assist in deciding how to invest in this technology. While the cost factor is often seen as a hurdle to the widespread adoption of AM in industries, there are situations where the benefits and value added by AM technology surpass the associated costs [21]. Additionally, AM has shown 25.4% annual revenue growth worldwide from $230 million to $1 billion over the past 25 years with aggressive forecast being $230 billion to $550 billion by 2025 [22]. [23] and [24] predicted that the cost of this emerging technology will be reduced over the next few years and this will make it easy for industries to adopt AM processes.

This paper reports on the results of an investigation into the technical and financial feasibility assessment of producing an impeller sand mould using a Voxeljet VX1000 printer. The evaluation exercise included the application of a casting simulation process and the financial payback period method. The simulation process studied the optimal method for producing the impeller sand mould by determining the method of the sand mould production before printing, and the design system of the final casting. The payback period (PP) calculated the time it would take to recover the initial investment once the rapid sand-casting process is adopted to produce impeller sand moulds. This information aims to assist the local foundry industry in making investment decisions regarding the adoption of rapid sand-casting technology.

2 Methodology

The methodology of this work consists of two parts, the technical analysis, and the financial analysis. The technical analysis of this study consists of two components, firstly, the 3D printing simulation to determine the mould orientation, size and printing parameters using the Magix software. Secondly, the casting methoding design to determine the gating and running system using the Magmasoft® software as shown in Figure 2. The financial analysis was essentially based on the assessment of the financial feasibility using the payback period technique with several assumptions presented and discussed in Section 3. The methodology was based on the case study of an impeller sand mould followed by the technical analysis, followed by cost modelling of printing the impeller sand mould to obtain the cash flows needed for the financial assessment.

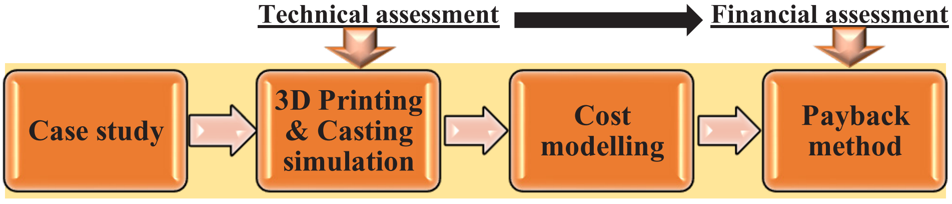

Fig. 2. The methodology of the study.

2.1 Case study

Figure 3 illustrates a 2D semi-open impeller for a centrifugal pump, used for the case study. The impeller is complex in design and can be printed with high dimensional accuracy using rapid sand casting. This impeller is of particular interest because of its complexity and because it is commonly used in the SA mining and foundry industries, which still use traditional casting methods to manufacture moulds. Its complexity in design is also based on its vanes which must be cast with high dimensional accuracy to optimise its performance. Rapid sand-casting methods, specifically binder jetting using the VX1000 printer, can be used to make such moulds.

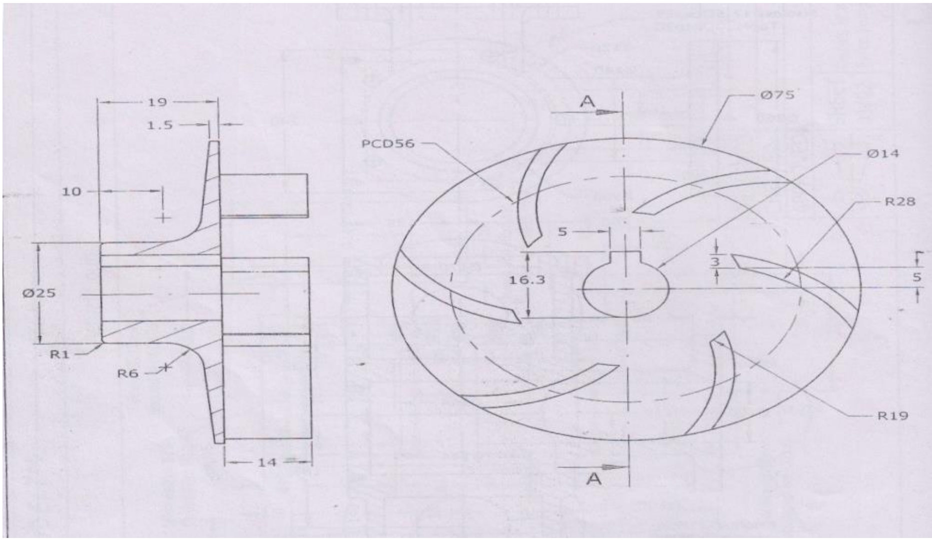

Fig. 3. 2D semi-open impeller casting drawing.

The VX1000 printer was used for the analysis and results of the study. Figure 4 shows the VX1000 printer's exterior (Image A) and its building platform (Image B). Figure 5 shows the VX1000 printer's virtual building platform according to the Magix software which virtually determined the orientation of the sand mould before printing. The VX1000 printer has constant building characteristics and properties, as given below:

- Length (L) = 1100 mm
- Width (W) = 637 mm
- Height (H) = 500 mm
- Layer thickness per printed layer (Lt) = 0.3 mm
- The time it takes to print a layer (Tl) = 35 seconds
- Volume per layer (Vl) = 0.21021 L
- Weight per layer (Wl) = 0.336 kg
- Silica sand density (Sd) = 1.6 kg/L
- A mixing ratio of silica sand when printing = 80% new sand and 20% old sand.

The main raw material or consumable that is used when printing with this machine at VUT is silica sand with 49.27% grain fineness number and the binder system is the furfuryl alcohol.

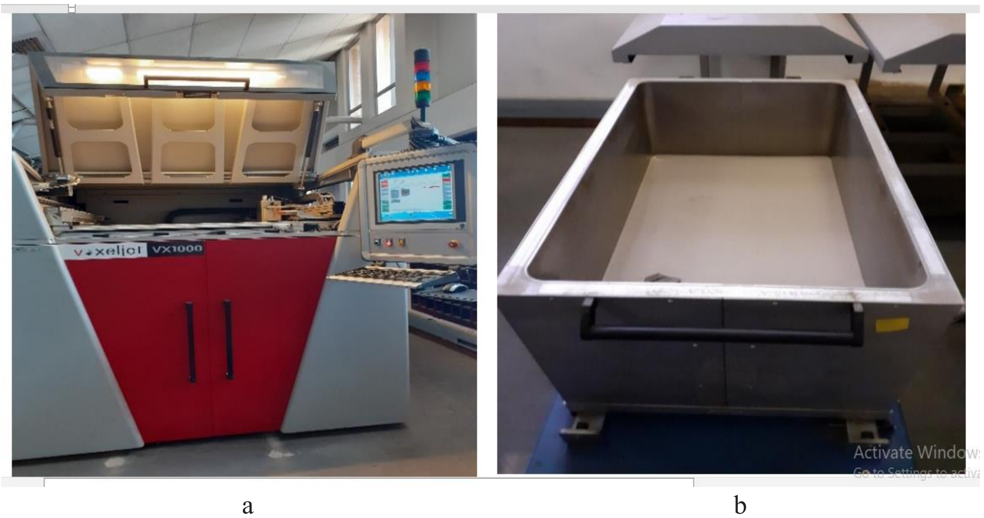

Fig. 4. (a) The VX1000 printer exterior and (b) its building platform.

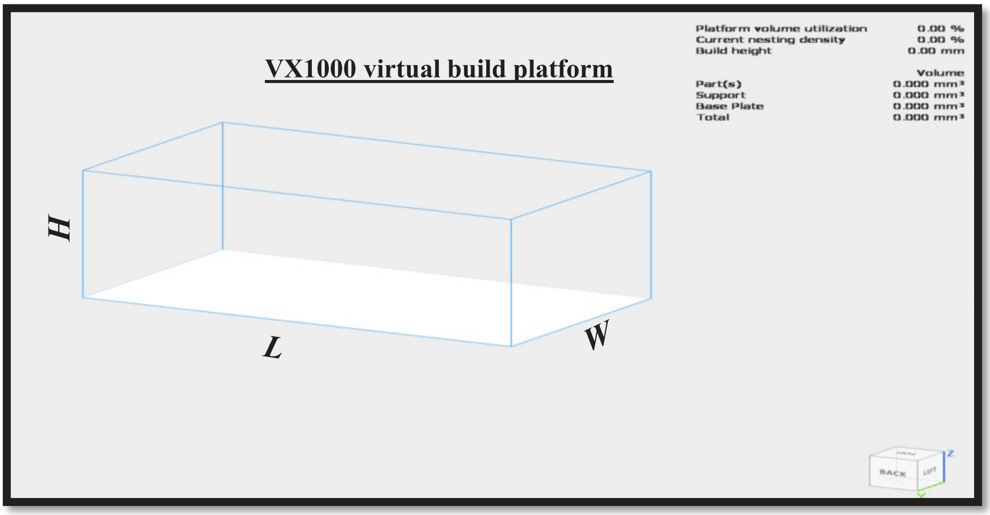

Fig. 5. The virtual building platform of the VX1000 printer.

2.2 Casting simulation

From the determined impeller, the casting simulation process analysis was performed using Magmasoft® (a simulation and virtual optimisation of casting processes), which studied the optimal geometric design of the sand mould and the final casting design. The geometric design included elements such as the feeder and the runner system; as well as the optimal casting design parameters for a sound casting with high yield and minimal or 0% predicted porosity on the final casting. Figure 6 shows the study's followed virtual casting design approach. This design optimisation based on computer-aided methods is valuable for both existing castings and those being developed for the first time, as it eliminates the need for shop floor trails, traditionally adopted in foundries, also illustrated in Figure 6.

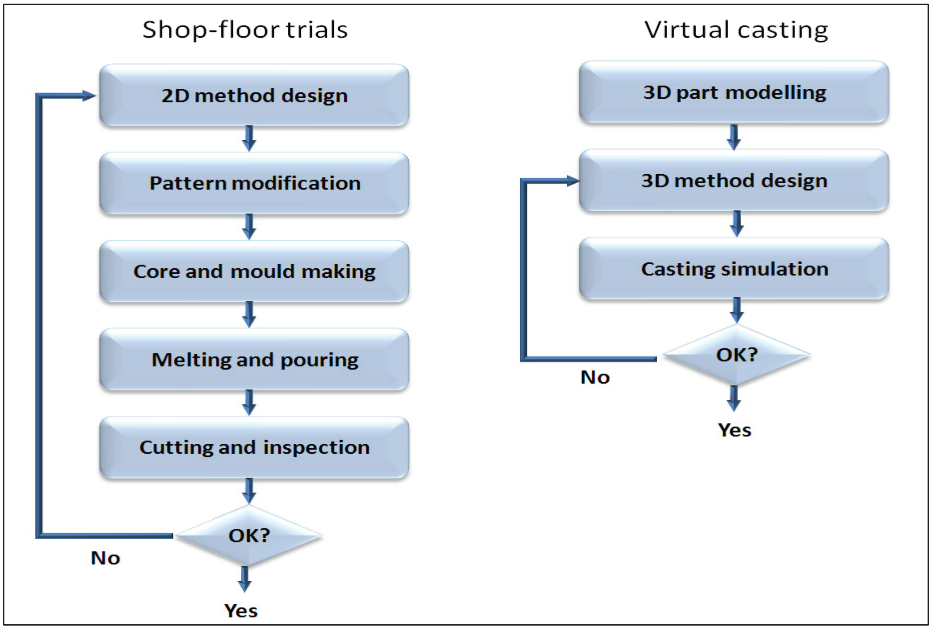

Fig. 6. Traditional design versus CAD method optimisation [25].

2.3 Cost modelling

Cost modelling is the process of generating an equation to calculate the cost of fabricating a product based on the material or consumables used for fabrication. Within this study, a cost modelling analysis was conducted to produce an impeller sand mould using the VX1000 printer. The analysis focused on four key components that significantly contribute to the overall direct cost of the printed sand mould. These primary components are the sand cost, binder cost, cleaner cost, and operational cost of the printhead, as illustrated in Figure 7. The sum of these four main costs, plus the markup and value-added tax (VAT) gave the price of printing the impeller sand mould.

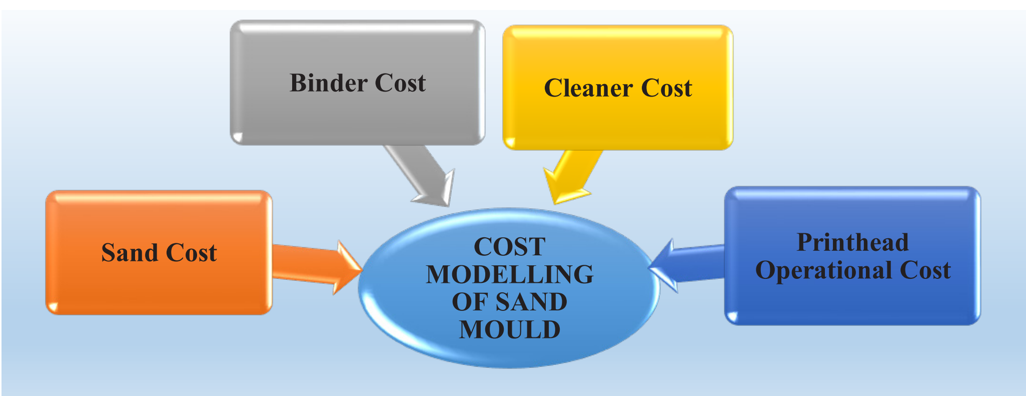

Fig. 7. The four main components used to cost model sand mould printing using the VX1000 printer.

Where:

- Sand cost (Scost) – was calculated from the VX1000 printer's length (L), its width (W), the height of the impeller sand (Hp), the silica sand density (Sd) and its mixing ratio (Mr) as shown in *Equation* (1).

$$\begin{aligned} Scost &= Sand\ used\ (Su) \times Sand\ cost\ per\ kg \\ &= Su \times Sand\ cost\ per\ kg \\ &= (((Hp \times Lm \times Wm)/1\,000\,000) \times Sd \times Mr) \times Sand\ cost\ per\ kg \end{aligned} \tag{1}$$

  At the time of the study, the cost of sand was R20.00 per kg.

- Binder cost (Bcost) – was calculated from the binder cost per litre, the binder per mm^3, the safety factor to account for any variability in binder usage per layer and the volume of the sand mould as shown in *Equation* (2).

$$Bcost = (binder\ per\ mm3\ (L) \times V \times binder\ cost\ per\ litre) \times (1 + safety\ factor) \tag{2}$$

  At the time of the study, the binder per mm^3 was 2.516 669 620 348 19 x 10^{-8} L, the binder cost per litre was R1 923.24 and the safety factor was 10%. The volume of sand mould was determined after the simulation using Magix software.

- Cleaner cost (Ccost) – was calculated from the cleaner cost per litre, the cleaner per layer and the total number of layers (Nl) to be printed, as shown in *Equation* (3).

$$Ccost = (Nl \times cleaner\ per\ layer) \times cleaner\ cost\ per\ litre \tag{3}$$

  At the time of the study, the cleaner per layer was 0.001 566 563 L, and the cleaner cost per litre was R44. The number of layers was determined after the simulation process using Magix software.

- Printer-head operational cost (PHcost) – was calculated from the time taken (Tp) to print the sand mould and the operational cost per hour, as shown in *Equation* (4).

$$PHcost = printhead\ cost\ per\ hour \times Tp \tag{4}$$

At the time of the study the replacement cost of the VX1000 printer was R750,000, its predicted lifetime was 6000 hours and, therefore, the operational cost per hour was R125 (i.e., R750,000/6000 hours). The time taken to print the sand mould was also determined after the STL file using the Magix software.

2.4 Payback period

The payback period is one of the financial metrics that can be used in evaluating a process's economic feasibility by calculating the time it will take to recover the initial investment or the price of purchasing the machine. Even though it sometimes does not account for the time value of money, it does give an idea of the time needed to break even, i.e., the number of years it will take for the invested amount to be recovered. This financial method is easily understood, even by non-financial personnel, and was calculated from the initial investment and the annual cash flows, as shown in equation (5).

$$Payback\ period = initial\ investment \div annual\ cash\ flows \tag{5}$$

2.4.1 Initial investment

The initial investment is the price of purchasing the printer. It is based on the model of the printer, including the additional job box, building space, unpacking stations, etc. For the VX1000 printer, the purchase price was R15,200,000.00 at the time of the study; and this was the initial investment for calculating the payback period.

2.4.2 Annual cash flows

Cash flow is defined as the amount of cash that is being transferred in and out of the company, with cash received representing cash inflows and cash spent representing cash outflows [26]. A firm's cash flows can be divided into operating cash flows and investment cash flows, which represent activities that generate revenues and activities related to purchasing a machine and other investments, respectively [27]. Cash flows can be studied or analysed monthly or yearly depending on the project or process being analysed. The gross profit cash flows (GPCF) were used as the main cash flows for this analysis. An income statement was generated as shown and detailed in Appendix A. These cash flows represent the direct cash flows related to the cost of producing the impeller sand mould, and they are a good indication of the profitability of the project or process. Figure 8 shows the processes that were followed to calculate the GPCF from an income statement.

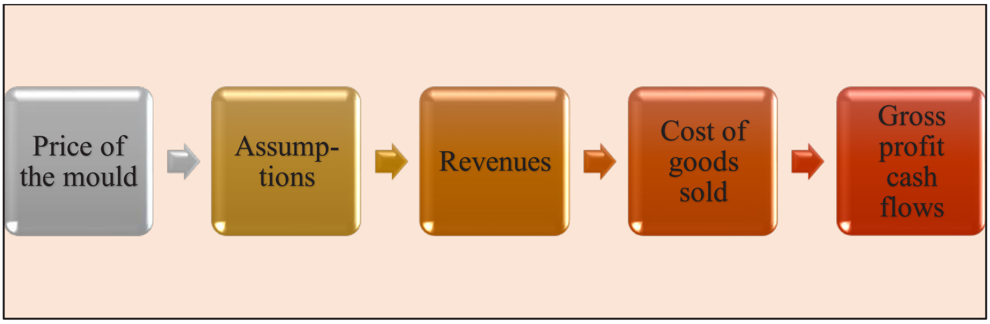

Fig. 8. Calculation of the gross profit cash flows from an income statement.

- The price of the mould was calculated from the cost of printing the mould plus the markup (based on benchmarking) and VAT. The study was analysed for five years to get the most accurate results from the analysis.
- Assumptions of generating the income statement included the number of impeller sand moulds that can be printed per year, the discount rate for discounting the cash flows per year, the inflation rate for escalation of the cash flows each year and the benchmarking from the gross profit margin ratio based on the manufacturing industry and used as the markup. The printer could print two moulds for 260 days per year (excluding holidays and weekends) per print based on the nesting density determined using Magix software analysis following the casting simulation analysis. The discount rate was 7% based on the South African interest rate, the inflation rate was 5% based on the average rate of inflation in South Africa from 2018–2023 and, lastly, benchmarking was 39.9%, which was used as a markup. Benchmarking data was used as a comparative performance measure of the foundry process, which was categorised as part of the manufacturing industry where the average median gross margin ratio from 2019–2023 was used as a markup.

- Revenue for year 1 was calculated from the price of the mould and the number of moulds that can be printed per year. Revenues were escalated with the 5% inflation rate from year 2 to year 5.
- The cost of goods sold (COGS) for year 1 was calculated from the cost of printing the impeller sand mould multiplied by the number of sand moulds printed per year. The COGS escalated with a 5% inflation rate from year 2 to year 5.
- Gross profit cash flows (GPCF) from year 1 to year 5 were calculated by subtracting the revenues (year 1 to year 5) from the COGS (year 1 to year 5).

3 Results

This section presents and discusses the results obtained from the technical and financial feasibility analysis of printing an impeller sand mould through the binder jetting process.

3.1 Casting simulation

Figure 9 shows the casting simulation results from Magmasoft® where the feeder was situated optimally at the centre and the runner at the corner of the sand mould. This orientation enhanced the ability to clean the impeller sand mould after printing; and this type of geometric design system also helped to avoid turbulence of the molten metal, which can result in poor surface finish of the final casting. The orientation of the sand mould from Magmasoft® also showed a good yield at 74.3% with a predicted 0% porosity on final casting (see Figure 10). Table 1 shows the optimised simulation results of the position of the feeder, the runner system, the yield and the predicted porosity results.

Table 1. Optimised casting simulation results by Magmasoft®.

Results	
Feeder height	50 mm
Feeder diameter	75 mm
Down sprue diameter	40 mm
Sprue offset from the centre	170 mm
Porosity in the casting	0% predicted
Yield of casting was 74.3% and broken up as shown below The total weight of the casting was 25.73 kg (solid)	
Final casting	19.11 kg
Machine allowance	2.05 kg
Feeder system	1.35 kg
Runner system	3.22 kg

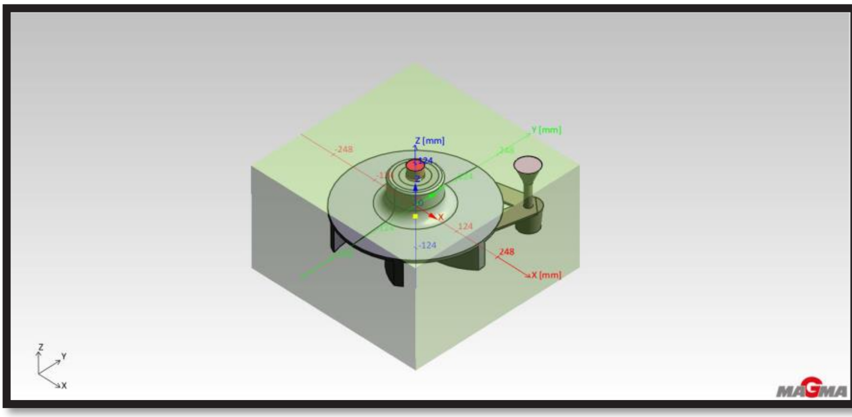

Fig. 9. Impeller sand mould design using Magmasoft®.

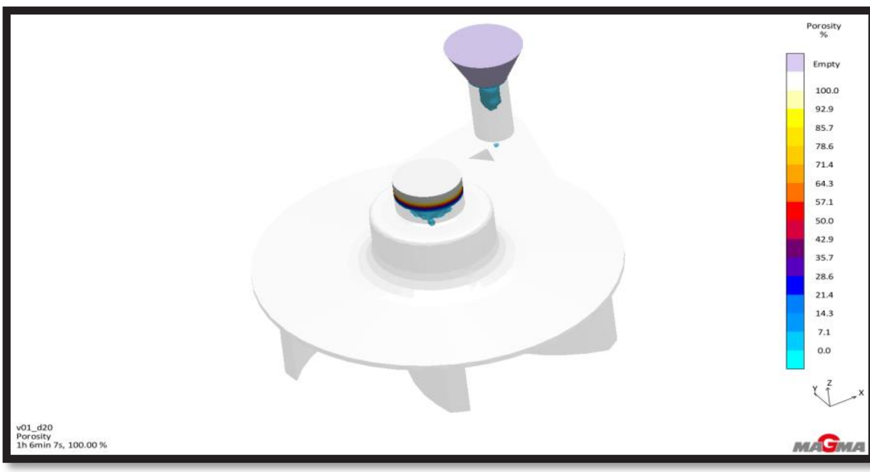

Fig. 10. Casting design of the impeller using Magmasoft®.

3.1.1 Orientation of the sand mould in the building platform

After the casting simulation, the Magix software was used to determine the printing position of the impeller sand mould in the machine building platform, as shown in Figure 11. This position showed how the impeller sand mould would be printed in the machine's building platform and Table 2 shows the printing parameters and the dimensions of the impeller sand mould. These parameters and dimensions include the length of the sand mould, its width, its height, its volume, the number of layers to be printed, the time it will take to print the impeller sand mould and the nesting density. The nesting density represents the percentage of space occupied by the entire sand mould in the machine-building platform. The nesting density of printing one mould in the building platform was 35.44% as determined by Magix software and is shown in Figure 11. Based on a nesting density of 69.96%, obtained after suitably stacking the impeller sand mould using Magix software, two impeller sand moulds could be printed in the machine, as shown in Figure 12. Table 3 shows the printing parameters and the dimensions of printing two sand moulds in the building platform. The height remained the same, therefore the number of layers also remained the same, only the volume changed due to the increased nesting density when printing two impeller sand moulds. The results of the cost modelling and the payback period for the study were based on printing two impeller sand moulds in the machine simultaneously.

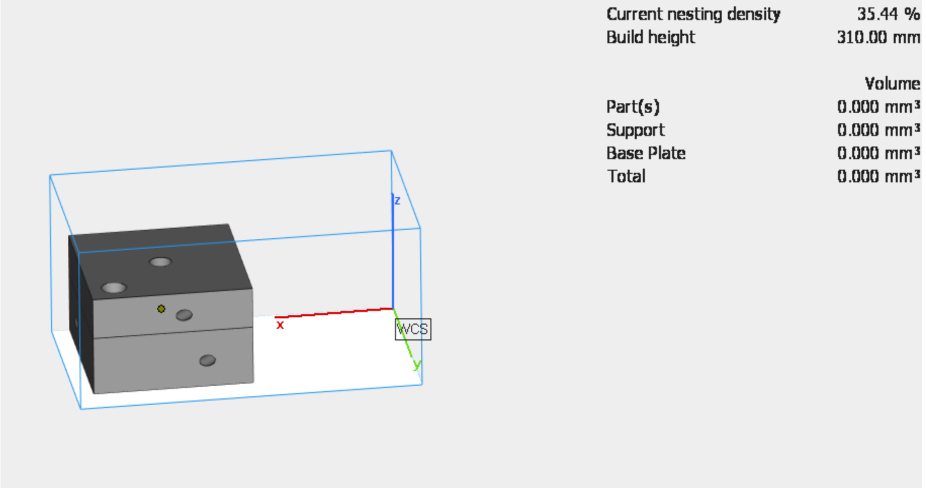

Fig. 11. Impeller sand mould positioned in the building platform.

Table 2. Impeller sand mould dimensions of the position in Figure 11.

Name	Value
Number of moulds in the building platform	1
Length	495 mm
Width	495 mm
Height	310 mm
The volume of the mould	68 968 964.568 mm^3
Nesting density	35.44%
Number of layers	1 050
Build time of the mould	10.21 hours

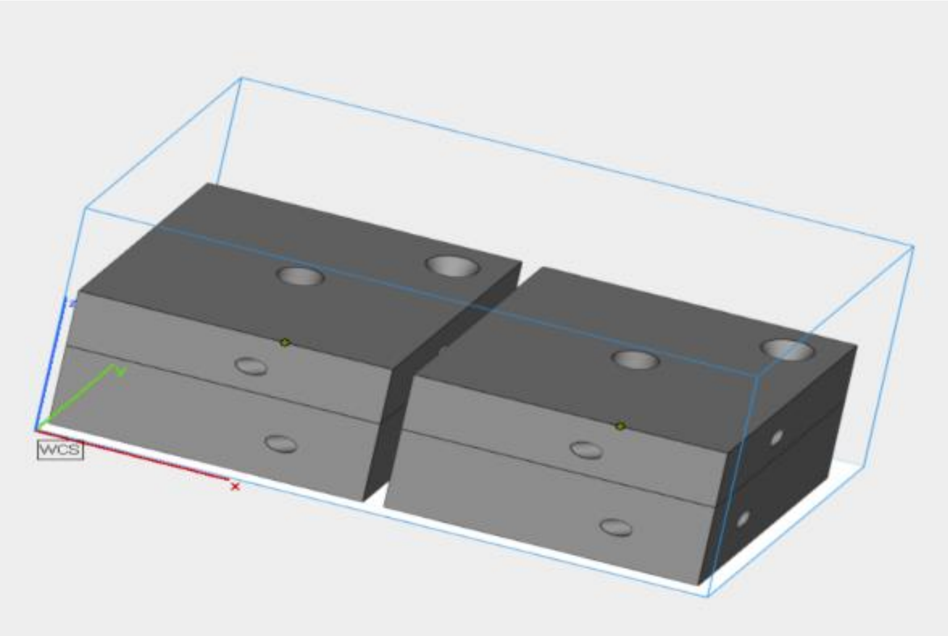

Fig. 12. Two impeller sand moulds positioned in the building platform.

Table 3. Impeller sand mould dimensions of the position in Figure 12.

Name	Value
Number of moulds in the building platform	2
Length	495 mm
Width	495 mm
Height	310 mm
The volume of the mould	141 087 929.136 mm^3
Nesting density	69.96%
Number of layers	1 050
Build time of the mould	10.21 hours

3.2 Cost modelling

Applying Equations 1, 2, 3 and 4 discussed in Section 2.2 for the Scost, Bcost, Ccost and PHcost, respectively, the resulting cost of printing the impeller sand mould using the VX1000 printer was R14 420.93, and the price of the impeller sand mould was R23 201.12.

3.3 Payback period

During the time of the study, the price of purchasing the VX1000 printer was R15,200,000.00, and the cash flows were calculated according to the income statement shown in Appendix A and the assumptions discussed in Section 2.4.2. Table 4 presents a summary of the 3 sections of the income statement and the gross profit cash flows. From the GPCF the payback was calculated using two cash flow methods, the annuity method, and the mixed stream method. The annuity cash flow method assumed constant cash flows for 5 years, and the mixed stream cash flow method assumed that the cash flows escalated each year based on the 5% inflation rate.

Table 4. Cost and price of the impeller sand mould.

			Annuity cash flows	Mixed stream cash flows
Year	Revenues	COGS	GPCF	GPCF
0	R0	R0	-R15 200 000,00	-R15 200 000,00
1	R12 064 581.94	R7 498 885.50	R4 565 696.44	R4 565 696.44
2	R12 667 811.04	R7 873 829.78	R4 565 696.44	R4 793 981.26
3	R13 301 201.59	R8 267 521.27	R4 565 696.44	R5 033 680.32
4	R13 966 261.67	R8 680 897.33	R4 565 696.44	R5 285 364.34
5	R14 664 574.75	R9 114 942.20	R4 565 696.44	R5 549 632.56

$$\begin{aligned} \textit{Payback Period (annuity cash flows)} &= \textit{Initial Investment} \div \textit{Annual Cash Flows} \\ &= \text{R15 200 000} \div \text{R4 565 696.44} \\ &= 3.33 \text{ years.} \end{aligned}$$

The payback period for mixed stream cash flows is different to that of the annuity cash flows.

- In year 1, R4 565 696.44 would be recovered from the R15 200 000.00 initial investment.
- In year 2, R9 359 677.70 would be recovered (R4 565 696.44 from year 1 and R4 793 981.26 from year 2).
- In year 3, R14 393 358.02 would be recovered (R4 565 696.44 from year 1, R4 793 981.26 from year 2 and R5 033 680.32 from year 3).
- At the end of year 4, R806 641.98 would have been recovered, only 15.26% (R806 641.98/R5 285 364.34 = 0.1526) of the year 4 cash flow of R5 285 364.34 would be needed to complete the payback of the initial R15 200 000.
- Therefore, the payback period of the mixed stream cash flows is 3.15 years, as shown in Figure 13.

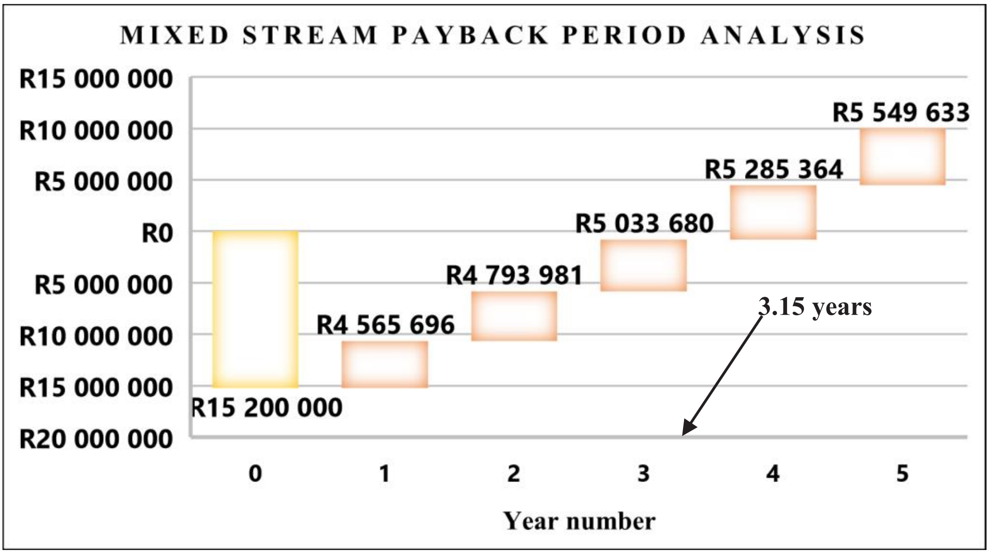

Fig. 13. Payback period analysis for the mixed stream cash flows

Depending on management's timeline for the recovery of the initial investment, the process of printing the sand mould using the binder jetting process of the VX1000 printer is economically feasible for adoption by the local foundry industry, as the payback period was within the study period of 5 years. Both the annuity and the mixed stream payback periods show that the R15,200,000 price can be recovered within 5 years, which is economically feasible unless management specifies a shorter period of recovery.

4 Conclusion

The purpose of the study was twofold: to conduct a technical analysis followed by an initial evaluation of the financial feasibility of producing an impeller sand mould using a binder jetting process using the VX1000 printer. The technical assessment, in particular, included a few simplification assumptions of the cost modelling limited to the direct 3D printer costs, including sand, binder, printer head and cleaner costs. The results from the simulation process gave the orientation of the impeller sand mould with optimised dimensions, including the feeder and the runner system, thus avoiding a poor surface finish and metal porosity while optimising the casting yield. The position and number of the impeller sand moulds that could be printed at one time were also determined based on the maximum capacity of the machine when printing the case study impeller sand mould. The financial feasibility results showed that the payback period for the annuity and mixed stream cash flows was within five years of the process analysis. Therefore, the direct cost related to the rapid sand casting process is feasible for adoption by the local foundry industry for printing sand moulds. On the other hand, the annuity cash flows showed that the initial investment could be recovered in 3.33 years, while the mixed stream cash flow would be recovered in 3.15 years. The study contributes to the national effort to demonstrate the benefits and economic feasibility of Rapid Sand Casting in South Africa.

5 Limitations

The study results were based only on the VX1000 printer, which prints sand moulds and cores using the binder jetting process. As such, the findings cannot be generalised to other AM processes and machines. In addition, the study was based on the assumption that the printer would be running at total capacity when printing these impeller sand moulds without breakdown or maintenance interruption. Finally, the analysis relied on a specific impeller as the case study and cannot be generalised to different moulds or cores.

6 Future work

This is a first research work on the feasibility of rapid sand casting using Voxeljet available at VUT. The study essentially provides an initial approach and preliminary results to the question making use of the payback period method based on the cost modelling and technical assumptions. Additional work will be required in the future to look closer to the industrial reality by digging deeper into the assumptions, including the cost of computer-aided design, simulation cost and the labour cost of the cleaning stage. The cost analysis will also encompass a comparison between the manufacturing costs of traditional sand moulds and those associated with the rapid sand casting process. In addition, future work is planned to print and cast this impeller sand mould using the VX1000 printer according to the casting simulation results obtained. Different impellers will also be considered for analysis and comparison to identify common aspects in the printing of sand moulds using this machine. Metallurgical analysis will also be considered, including the surface finish and the porosity analysis of the final casting after the printing and casting of the impeller. The payback analysis for the printing of different impeller sand moulds with different dimensions will also be done to compare how differences in dimensions impact the assumed cash flows, and ultimately the payback period. Future work is also considered to include the costing analysis of printing sand moulds using locally sourced silica sand and determining the payback period based on local silica sand.

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Appendix A

Income statement

The volume of the impeller sand mould	141 087 929.14 mm^3
The total cost of producing sand mould R14 420.93	R14 420.93
Price of the sand mould	R23 201.12
Sand moulds printed per day	2 per print
Total number of operational days per year	260 days
Total moulds produced per year	520 moulds (2 moulds per print × 260 days)
Average inflation rate (from 2019 to 2023)	5%
Discount rate	7%

Period	0	1	2	3	4	5
Year	2018	2019	2020	2021	2022	2023
Revenues		R12 064 581.942	R12 667 811.041	R13 301 201.591	R13 966 261.671	R14 664 574.754
Cost of goods sold		R7 498 885.503	R7 873 829.789	R8 267 521.278	R8 680 897.331	R9 114 942.207
Gross profit cash flows		R4 565 696.439	R4 793 981.261	R5 033 680.324	R5 285 364.340	R5 549 632.567
Annuity GPCF	-R15 200 000.00	R4 565 696.439	R4 565 696.439	R4 565 696.439	R4 565 696.439	R4 565 696.439
Mixed stream GPCF	-R15 200 000.00	R4 565 696.439	R4 793 981.261	R5 033 680.324	R5 285 364.340	R5 549 632.567