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DECISION SUPPORT FOR 3D PRINTER SELECTION IN MANUFACTURING PROTOTYPING: AN AHP-BASED MULTI-CRITERIA ANALYSIS

Abstract: *The increasing complexity and dynamism of market demands necessitate rapid and efficient processes in manufacturing. 3D printing enables reduced prototyping time which can help companies to survive and be competitive. There are different additive manufacturing techniques such as fused deposition modeling (FDM), laminated object manufacturing (LOM), selective laser sintering (SLS), stereolithography (SLA) etc. Also, there are different 3D printers at the market. However, selecting an optimal 3D printer requires careful consideration of technical, economic, environmental, and performance criteria. This study employed the analytical hierarchy process (AHP) to evaluate and rank four 3D printer models available in Serbia based on five criteria. Sensitivity analysis confirmed the robustness of the decision-making model, with the highest-ranked alternative consistently maintaining its position under varying weight scenarios. The results demonstrate the utility of AHP in providing structured, reliable guidance for 3D printer selection, enabling manufacturers to enhance their prototyping capabilities efficiently.*

Keywords: *3D printer, selection, AHP*

1. Introduction

The modern way of doing business in the production sector, which is characterized by strong competition and large and constantly changing market demands, requires companies to have an agile and efficient approach in all business segments. 3D printing technology enables businesses to reduce the time required for prototyping, more efficient use of materials and reduction of waste, which certainly leads to greater competitiveness of the companies. Additive manufacturing (AM), also known as 3D printing, means turning a digital model to an object by building them layer-by-layer (Cetnikaya et al., 2017; Neuenfeldt Júnior et al., 2024). The additive manufacturing method, which is considered a new industrial revolution, results in the flexible and rapid production of customized structures without spending a lot of money on changing production tools and processes (Dong-Woo et al., 2015).

There are a lot of 3D printers on the market today that have different specifications. For proper selection of 3D printer it is necessary to take into account numerous criteria (production time, price, 3D printers build volume, resolution, environmental impacts, etc). Otherwise, the choice can be poor. The application of the multi criteria decision

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making (MCDM) methods for assessment and selection of 3D printer, where all relevant criteria can be considered, can lead to relevant decision. There are numerous MCDM methods applied in theory and practice such as: analytical hierarchical process (AHP), analytical network process (ANP), preference ranking organization method for enrichment of evaluations (PROMETHEE), technique for order of preference by similarity to ideal solution (TOPSIS). AHP is one of the most used method for solving decision making issues in numerous fields: energy (Stojčetović et al., 2023), environment (Kurttila et al., 2000), tourism (Stojčetovic et al., 2019).

Also, AHP is used to select 3D printers. Netto et al. (2019) used AHP method and three groups of criteria: technical performance criteria (surface roughness, dimensional and geometric accuracy and build time), economic aspects (unit price and cost of the material consumed) and the software capabilities (build time and material consumption estimation) to assess and select three different 3d printers. Aka (2023) used spherical fuzzy analytic hierarchy process (SF-AHP) method in his study and included seven criteria as accuracy, complex design, surface quality, ease of use, throughput, material cost, and equipment cost for selection among three technologies as fused deposition modeling (FDM), selective laser sintering (SLS), and stereolithography (SLA). Raja et al. (2022) applied AHP for selection among three FDM machine using criteria such as price, size/volume, extruder type, and weight of the machine. It can be concluded that AHP has been successfully used alone or in combination with other methods for the selection of 3d printers in various fields. Also, the advantages of the AHP methodology can be mentioned, such as: ease of use, the possibility of group decision-making, the availability of software tools that can further facilitate and speed up the application of the method, the possibility of combining with other methods to improve performance, decomposition of a complex problem into components and clearer insight into the essence of the problem, etc. Because of all the above in this paper, process of the 3D printer selection is conducted using AHP method.

The goal of this paper is to select the optimal 3D printer for prototyping for a manufacturing company based in Serbia.

2. 3D technologies and printing

Numerous 3D printing processes and technologies have been invented since the inception of 3D printing.

The fused deposition modeling (FDM) method was developed in the late 1980s. Fused deposition Modeling (FDM) is the first example of a material extrusion system (Stansbury & Idacavage, 2016). Using this technique the models are created by extruding small grains of material that harden and form layers. With FDM can be applied a numerous materials, such as thermoplastics like PLA and ABS, engineering materials such as TPU and PETG, and highperformance thermoplastics like PEEK, PEI, and ULTEM. FDM is one of the fastest growing 3D technologies and an extensively used additive manufacturing process for the production of prototypes in numerous engineering applications (Kozior et al. 2020). Particularly, manufacturers of specific products favor FDM technology due to its versatile range of print able materials, which are especially well-suited for prototyping purposes (Ferretti et al. 2022;).

Laminated object manufacturing (LOM) is a method of 3D printing used to produce objects by layering paper, plastic, and metal, where process involves layering paper or plastic laminates together and cutting the object into the desired shape using a laser cutter (Đurović, et al. 2024). In comparison to other 3D technologies, the surface quality and dimensional accuracy of LOM generated models do not reach the highest quality.

Selective laser sintering (SLS) was created in the mid-1980s is a fast manufacturing method that fuses particles using high-powered CO_2 lasers, where the laser fuses powder materials (metal, ceramic, or polymer materials like white nylon powder) through a process called sintering (Đurović, et al. 2024).

Stereolithography (SLA) was first developed in 1981. SLA is only being utilized to structure one material at a time, and when comparing to other additive manufacturing, typical SLA processes exhibit superior resolution and better surface qualities but at slower printing times and higher cost (Schmidleithner & Kalaskar, 2018). SLA utilizes a variety of materials with diverse characteristics such as soft, transparent, highly stable, and heat-resistant materials (Msallem et al. 2020).

Selective Laser Melting (SLM) is utilized to create metal components from metallic powders using a high-intensity laser as an energy source in a powder bed fusion process where the laser melts and fuses specific areas of the powder based on computer-aided design (CAD) data, layer by layer (Đurović, et al. 2024).

When it comes to 3D printing technologies, certain advantages and disadvantages can be stated about each of them (Table 1).

Table 1. Advantages and disadvantages of 3D printing technologies (Jeong et al., 2024)

3D technology	Advantages	Disadvantages
Stereolithography (SLA)	- Quick production speed - Precise and highly accurate - Can accommodate complex designs - Numerous material options	-Can be slower production compared to other printers -High post-processing requirements
Digital Light Processing (DLP)	-High speed -Precise and highly accurate -Can accommodate complex designs -Numerous material options	-Arguably lower quality than other printers -Limited by voxel size
Fused Deposition Modeling (FDM)	-Cheaper technology -Great layer bonding	-Only thermoplastic materials
Selective Laser Sintering (SLS) and Selective Laser Melting (SLM)	-Can print polymers or metals -Batch production -No supports needed	-Requires high printing infrastructure -Use of fine powders can he hazardous
Photopolymer Jetting	-Extremely high resolution -Can print with multiple colors on one single print	-Low mechanical properties -Limited heat resistance -Costly maintenance of printer heads
Powder Binder Printing	-Wide range of unique materials. -High speed printing	-Low mechanical properties -Low resolution -High waste of material
3D Laser Bio-Printing (LAB)	-Only option to print living cells and other biomaterials -Completely unique	-Costly -Very specific conditions to produce viable biomaterials

3. Methodology

Methodology for 3D printer selection can be conducted through four steps:

Step 1. Define decision making goal – at the beginning, it is necessary to define the goal of the decision making (for example, selection of the cheapest, fastest, highest quality 3d printer etc) which depends on the needs of the decision maker.

Step 2. Define list of 3D printers to be selected and list of decision making criteria – in the second step, it is necessary to define a list of 3D printers that will be the subject of evaluation and decision making. Also, in order for the decision to be made, it is necessary to define a list of criteria based on which the 3D printer will be evaluated.

Step 3. Assessment using AHP – after defining the list of 3D printers and criteria, the AHP method can be applied for evaluation and ranking. The AHP method is described in more detail in the text that follows.

Step 4. Sensitivity analysis - The sensitivity analysis is to be performed after obtaining the decision making results to confirm how changes in the weight factor influence the ranking of alternatives.

The AHP was developed by Saaty T.L. (1980), and the AHP methodology can be explained step by step approach as following:

1. In the first step, the problem is formulated in a hierarchical manner. In this step, the aim, main criteria, sub criteria and alternatives should be identified clearly.
2. Paired comparisons are performed and the relative importance are determined.
3. The consistency of pair wise comparison matrices is determined. If the consistency ratio (CR) is equal or smaller than 0.1 value, the comparisons are consistent.
4. In the final step, priorities of alternatives are found by combining the weights of criteria and the ratings of the alternatives.

To perform a pair wise comparison by all relevant criteria/alternatives, an *nxn* matrix A is formed:

$$A=\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

where a_{ij} values are obtained using a 9-point scale (Table 2).

Table 2. Saaty's 1-9 scale of pairwise comparisons

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong	An activity is favored very strongly over another
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, ,4, 6, 8	Intermediat e results	They are used to present a compromise between the priorities listed above

Matrix A is a positive reciprocal matrix in which aij represents the relationship of preference of alternative i and in relation to alternative j. The value of a_{ij} is the reciprocal of the value of a_{ji}. That is,

$$a_{ij} = \frac{1}{a_{ij}}.$$

If the pairwise comparisons are consistent, then the elements of the matrix A satisfy the equation:

$$a_{ij} * a_{jk} = a_{ik}, \text{ for each } i, j, k.$$

The weighting factor of the criterion / alternative can be denoted by w_i. If the matrix A is consistent a_{ij} can be represented as

$$a_{ij} = \frac{w_i}{w_j} \text{ for each } i \text{ and } j.$$

Therefore, if A is consistent then it is:

$$A*W=\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} * \begin{pmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{pmatrix} = n* \begin{pmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{pmatrix}$$

By normalizing the matrix $A = [a_{ij}]nxn$ the weight factor is calculated as follows:

$$a*_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}},$$

for each j=1,2,…,n. Then, it is:

$$w_i = \frac{\sum_{i=1}^{n} a_{ij}}{n},$$

for each j=1,2,…,n.

To determine the level of consistency, Saaty proposed the Consistency Index (CI), which can be calculated according to the following equation:

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)},$$

where λ_{max} is the validation parameter in AHP. The closer the value of λ_{max} is to n, the more consistent the estimate is.

The Consistency Ratio (CR) can be calculated by the following formula:

$$CR = \frac{CI}{RI},$$

where RI (Random Index) is a random consistency index.

When CR <0.10, the matrix can be assessed as acceptable, otherwise, the matrix should be modified until an acceptable value is reached. Homogeneity of factors within each group, fewer factors in the group, and better understanding of decision problems can improve the consistency index (Saaty, 1993).

4. Case study

As already mentioned in chapter 3, a 4-step model is proposed in this paper for the selection of 3D printers.

Step 1. Define decision making goal – in this paper goal is to select the optimal 3D printer for a production company from Serbia that needs a 3D printer for prototyping.

Step 2. Define list of 3D printers to be selected and list of decision making criteria – there are numerous 3D printers and technologies (FDM - *Fused Deposition Modeling*, SLA - *Stereolithography*, SLS - *Selective Laser Sintering*) etc. available at the market today. FDM technology has been increasingly used in industries as diverse as medical, electronics, and automobiles (Shafaat & Rezaei, 2021). Also, according (Aka, 2023) FDM has been becoming affordable for small businesses. Warnier et al. (2014) stated that many different types of materials are used for FDM printing, such as nylon, ABS, PLA, and polycarbonate. Due to all of the above, as well as the decision maker's opinion, FDM technology was chosen. After the selected technology, it was necessary to research the market of 3D printers in Serbia. It can be said that this segment of the market is still developing and that there is not too much supply or competition among companies selling 3D printers. After the market analysis, the 3D printers shown in the Table 3. were selected. When is about decision making criteria for 3D printer selection, different criteria are used in literature (Table 3). In some cases, these criteria are grouped (for example: technical, economic, environmental group of criteria) and within these groups there is a greater or lesser number of criteria, which most often depends on the needs of the decision maker. Although it can be expected that the decision-making results will be more precise if a larger number of criteria is used, this may not always be the case. Because a larger number of criteria can obscure the real picture of the decision maker. Therefore, it is important that the relevant criteria that directly affect the decision-making goal are included in the decision-making process. Criteria used in this paper are presented in Table 3 and 4.

Table 3. 3d printers and criteria

	Felix pro L dual extruder	Felix pro xl dual extruder	Creatbot D600 pro	Raise 3d pro3 plus
Price (min)	1,110,000	1,908,000	1,550,000	975,000
Operating volume (max)	300 x 400 x 400 mm	*600x400x600mm*	*600x400x600mm*	255×300×605 mm
Positioning Precision (max)	XY, 1.6, Z: 0.15 mikrona	XY, 1.6, Z: 0.15 mikrona	XY5.08 μm Z 1.25 μm	X 0.78125, Y0.78125, Z0.078125 micron
Max. Nozzle Temperature max	280 °C	280 °C	420 ℃	300℃
Max printing speed (Max)	150 (max)	150 (max)	120 mm/s	30–150 mm/s

Table 4. Criteria used in literature for 3D printer selection

Criteria group	Criteria	Reference
Technical	Easy menu usage Weight Automatic calibration Multi extruders Filament diameter WI fi availability	Çetinkaya et al, 2017
	Build time Surface roughness Dimensional accuracy Geometric accuracy	Justino Netto et al., 2019
Economic	Price Energy consumption Compulsion of uniform filemant usage	Çetinkaya et al, 2017
	Unit price Cost of the material consumed	Justino Netto et al., 2019
Environmental	Noise emission CO_2 emission Waste amount	Çetinkaya et al, 2017
Performance	Production time Setup time Capability of high volume production	Çetinkaya et al, 2017
Software capabilities	Build time estimation Material consumption estimation	Justino Netto et al., 2019

Step 3. Assessment using AHP - after selecting the 3D printer and defining the criteria that will be used in the decision, it is necessary to evaluate and rank the 3D printers. In this paper, the AHP methodology was applied for the assessment of 3D printers and their ranking. Table 5 presents pairwise comparisons for 3D printers according to each of the five criteria. Also, a comparison of the criteria in relation to the goal was conducted, where it can be seen that all criteria have equal importance. The degree of inconsistency in each pairwise comparison is within the allowed limits (<0.1).

Table 5. Pairwise comparison

Comparison of alternatives vs C1 (inconsistency 0,07)					Comparison of alternatives vs C2 (inconsistency 0,02)				
	A1	A2	A3	A4		A1	A2	A3	A4
A1	1	4	3	1/3	A1	1	1/6	1/6	2
A2		1	1/3	1/5	A2		1	1	6
A3			1	1/4	A3			1	6
A4				1	A4				1
Comparison of alternatives vs C3 (inconsistency 0,02)					Comparison of alternatives vs C4 (inconsistency 0,02)				
	A1	A2	A3	A4		A1	A2	A3	A4
A1	1	1	1/3	3	A1	1	1	1/5	½
A2		1	1/3	3	A2		1	1/5	½
A3			1	5	A3			1	5
A4				1	A4				1
Comparison of alternatives vs C5 (inconsistency 0,02)					Comparison of criteria in relation to the goal				
	A1	A2	A3	A4		C1	C2	C3	C4
A1	1	1	2	3	C1	1	1	1	1
A2		1	2	3	C2		1	1	1
A3			1	3	C3			1	1
A4				1	C4				1

After the pairwise comparison, all results were integrated and the final ranking of alternatives (3D printers) was obtained, which is presented in Figure 1.

According to the obtained results, the best ranked alternative is A3 (0.362). At the same time, the degree of inconsistency is within acceptable limits (0.01 < 0.1).

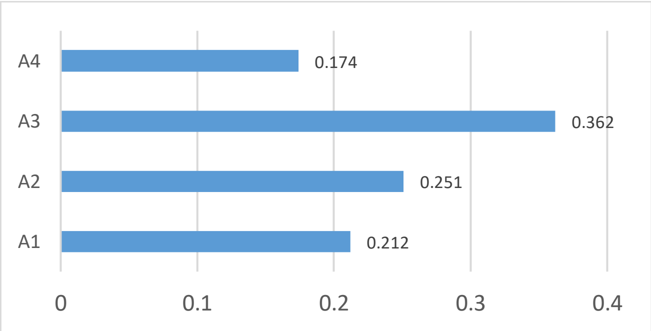

Figure 1. Final rank of alternatives (Inconsistency 0.01)

Step 4. Sensitivity analysis - After obtaining the decision results, a sensitivity analysis was carried out. The goal of this analysis was to determine how the change in the weight coefficients of the criteria will affect the changes in the ranking of the alternatives. Table 6 shows the minimal changes that lead to a change in the ranking of alternatives. It can be seen that significant changes in the value of the weighting coefficients of the criteria are needed in order to change the rank. However, despite this, the ranking of alternative A3, which is ranked first according to decision-making results, remained in first place in all scenarios. Also, maximum changes in the weight coefficient of criterion C3 do not lead to any changes.

Table 6. Sensitivity analysis

Criteria	Minimal change (+ or -)	New rank
C1	+13,6	A3-A4-A1-A2
C2	-10.7	A3-A1-A2-A4
C3	maximum decrease or increase does not lead to change	/
C4	-14.7	A3-A2-A4-A1

5. Conclusion

Modern market demands require fast and efficient processes, and 3D printers can significantly contribute to the acceleration of the prototyping process. However, there are many different technologies and models of 3D printers on the market, which requires a detailed analysis to select the right device. In the paper, an analytical hierarchical process was used for the evaluation and selection of four different 3D printers using five criteria. Also, a sensitivity analysis was carried out in order to determine the impact of the change in the weighting coefficients of the criteria on the ranking of the alternatives. It was found that the first-ranked alternative in all scenarios still remains in first place, which indicates that the decision-making model is stable and that the obtained results are reliable. Based on the obtained results, it can be concluded that the AHP method was successfully applied for the selection of 3D printers, providing clear guidelines to decision makers.

This paper can be a good starting point for selecting a 3D printer in manufacturing companies that can be adapted and improved according to the needs of specific companies, which can contribute to their more efficient business and improvement of competitiveness.

Possible improvements of this paper can also be considered. A larger number of criteria could be included in future papers. In order to avoid errors in decision-making, it is recommended to conduct decision-making in a fuzzy environment. Also, group decision-making would further improve the quality of the obtained results.

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