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STUDY ON AI-GENERATED 3D PRINTED ABS PARTS: INFLUENCE OF INFILL TYPE AND PERCENTAGE USING FACTORIAL ANOVA, REGRESSION, AND MULTI-OBJECTIVE OPTIMIZATION

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Abstract: *This study presents a comprehensive factorial analysis and ANOVA-based approach to optimizing 3D printing efficiency by investigating the impact of infill type and infill percentage on printing time and material consumption. The research integrates text-based and code-based CAD generation based on AI tools for designing the 3D printed part, followed by statistical evaluation using MATLAB. The results provide useful insights into balancing print speed and material utilization, enhancing additive manufacturing efficiency. The material used for the investigated printed parts is ABS.*
Keywords: *3D printing, CAD Automation,* ANOVA, *Multiple Linear Regression, Optimization.*

1. INTRODUCTION

Smart manufacturing uses a set of new technologies to improve the efficiency, flexibility, and sustainability of production processes. It is related to the broader concept of Industry 4.0 [1].

Additive manufacturing (3D printing) is one of the methods that has gained significant attention from researchers, particularly in polymer manufacturing and leads to the creation of complex, customized parts while reducing waste and lead time [2, 3]. It has revolutionized product development by enabling rapid prototyping and customization. However, optimizing print time and material usage remains a critical challenge [4, 5].

This interest conducted to the exploration of various materials and the development of multiple 3D printing techniques, including Fused Deposition Modeling (FDM), selective laser sintering (SLS), and stereolithography (SLA), among others [6, 7].

In order to optimize the final manufacturing process the selection of the optimal materials, type of printer, type of infill and infill percentage is important.

In the FDM process, continuous thermoplastic filaments are heated and extruded through a nozzle, allowing the layer-by-layer construction of objects. Most common materials used in FDM include Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) [5].

The FDM technique begins with the creation of a virtual model, which is sliced into 2D cross-sections based on the desired layer height.

Infill percentage in FDM ABS printed parts is viewed as an important factor that affects the part's strength, weight, and printing time [7, 8]. Higher infill percentages making it ideal for parts that need to withstand significant forces. In case of lower infill percentages, the weight of the part is reduced, which can be beneficial for applications where lighter parts are required.

This study employed a factorial design methodology, analyzing both categorical and continuous variables using ANOVA and Multiple Linear Regression (MLR) techniques [9, 10].

The CAD component was created using a combination of text-based parametric scripting and traditional CAD software, providing flexibility and consistency throughout the design process. A set of data was collected and processed in MATLAB to evaluate the statistical significance (p-values) of printing parameters and their interaction effects.

With help of statistical modeling combined with the additional integration of text-based and code-based CAD tools for part generation, this article evaluates the effects of infill type (rectilinear, gyroid) and infill percentage (5%-30%).

The 3D model was generated using AI instead of using CAD software. This approach intends to reduce the time of the design stage and to test the capability of this technology. Other researchers [11, 12] performed other similar approaches.

The 3D part model was considered and designed for evaluating the influence of rectilinear and gyroid type of infill and infill percentage over the wall thickness and height. A set of 12 ABS parts were printed using Prusa printer for conducting the experiment.

Two types of infill percentages were considered for the test part, which is non-functional, which are 5% and 30%.

For a better evaluation of the influence of these parameters, we considered a factorial experiment.

2. AI-GENERATED PART, 3D PRINTING AND DIMENSIONAL MEASUREMENT.

For generating the 3D model of the investigated part, we used the open-source Code-based editing and Text-to-CAD Modeling App [13]. The program uses machine learning and design API tool to analyze training data and generate CAD files. The code used for generating the 3D model is presented in Figure 1. As a result, it can be seen the 3D generated model in Figure 2.


KCL Code

```
// The 3D test piece .

@settings(defaultLengthUnit = mm)

// Define constants
baseLength = 50
baseWidth = 50
baseHeight = 5
wallThickness = 3
wallHeight = 15
cylinderHeight = 5
cylinder1Diameter = 10
cylinder2Diameter = 5
cylinder1Radius = cylinder1Diameter / 2
cylinder2Radius = cylinder2Diameter / 2
cylinderOffset = 11
```

Fig. 1. Text to CAD generating code.

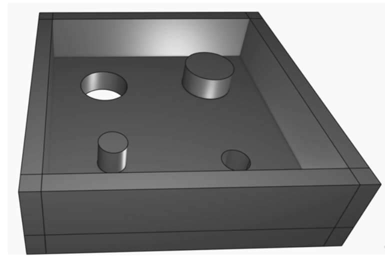

Fig. 2. The 3D CAD part generated.

Code-based editing enabled precise control over part dimensions and geometric constraints, facilitating quick design modifications and iterations. This hybrid approach ensured a CAD workflow that was accurate, reproducible, and flexible for generating parts.

"Prusa" type of printer was used for printing the part (Fig. 3).

Based on the research regarding the infill percentage we can conclude that it has a substantial impact on the mechanical properties of the parts [14, 15].

As the part is just a model for testing and it does not require any strength, we used the rectilinear and gyroid type of infill with infill percentage of 5 and 30% (Fig. 4).

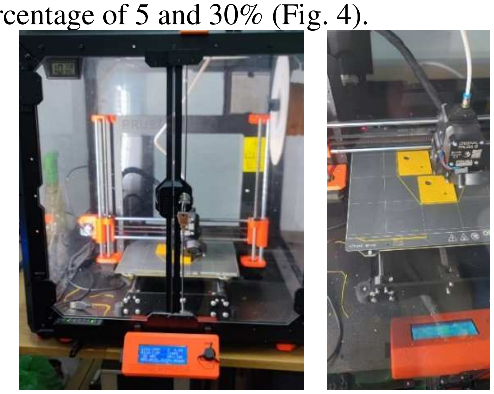

Fig. 3. Prusa 3D printer used for printing the parts.

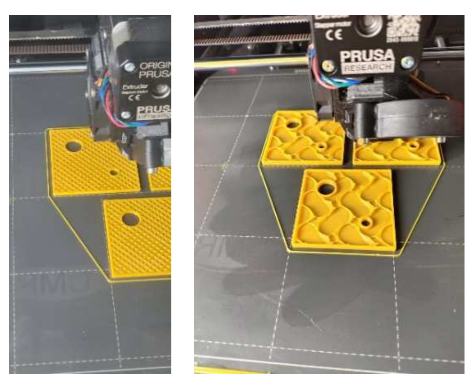

Fig. 4. The two types of infill: rectilinear (left, 30%) and gyroid (right, 5%).

Determining the appropriate infill percentage requires considering factors such as functionality, weight, material consumption, cost, printing time, and infill patterns. The dimensional measurements are presented in Figure 5.

Infill Type	Infill [%]	Time [min	Material [g]	Wall Diff [mm]	Ø Diff. Cyl. 10 [mm]	Ø Diff. Cyl. 5 [mm]	Ø Diff. Hole 10 [mm]	Ø Diff. Hole 5 [mm]
Rec	5	165	29.67	-0.1425	-0.0667	0.0267	0.4600	0.4133
Rec	5	165	29.67	-0.0975	0.1067	-0.1433	0.4600	0.3533
Rec	5	165	29.67	-0.1350	0.0600	0.0400	0.4467	0.3833
Rec	30	191	37.65	-0.0800	-0.0933	-0.0033	0.5133	0.3900
Rec	30	191	37.65	-0.1700	-0.0233	0.0467	0.3900	0.3433
Rec	30	191	37.65	-0.1025	0.0633	-0.0167	0.3233	0.4067
Gyroid	5	158	36.15	-0.0675	-0.2200	0.1133	0.4533	0.4133
Gyroid	5	158	36.15	-0.1125	0.0033	0.1167	0.4967	0.4000
Gyroid	5	158	36.15	-0.0750	0.1500	0.0800	0.5467	0.3633
Gyroid	30	219	45.25	-0.1525	0.0500	-0.0033	0.4700	0.4533
Gyroid	30	219	45.25	-0.1475	0.0200	-0.0200	0.4033	0.4267
Gyroid	30	219	45.25	-0.1150	0.0033	0.0333	0.5100	0.4433

Fig. 5. Data - dimensional measurement.

3. FACTORIAL ANALYSIS

We propose a factorial analysis type of experimental design to investigate the effects of the type of infill and infill percentage for improving the printing time and material consumption.

The experiment starts with 12 ABS pieces (4 combinations × 3 replications) with a layer thickness of 0.2 mm, like the one in Figure 6.

For the analysis of the printed part, we considered different infill percentages and observed how they influence:

- Geometric dimensions – potential variations caused by filament shrinkage or weak layer support.
- Printing time – how long each configuration takes.
- Material consumption – how much filament is used in each case.

The analyzed parameters are infill percentages of 5% and 30% and infill patterns (gyroid and rectilinear).

Geometric and Kinematic parameters	Values
Infill	200 mm/s
Layer height	0.2 mm
Angle of infill	45°
Layers of vertical shell	2 mm
Layers of horizontal shells	5 to 4 mm (top to bottom)
Speed for small perimeter	25 mm/s
Speed for external perimeter	35 mm/s

Fig. 6. Prismatic cuboid printed and few geometric and kinematic parameters.

The test piece is a prismatic cuboid with dimensions 50 × 50 × 30 mm (Length × Width × Height) (figure 6). It consists of a 5 mm thick base (50 × 50 mm), vertical walls with a thickness of 3 mm and a height of 15 mm.

It includes also two cylinders with diameters of 10 mm and 5 mm and a height of 15 mm and two cylindrical holes with the same diameters.

The centers of the cylinders and holes are symmetrically positioned relative to the center of the piece, at 11 mm along the X and Y axes.

4. RESULTS

A detailed interpretation and explanation of the factorial analysis and ANOVA models performed in MATLAB for optimizing 3D printing efficiency, focusing on printing time, material consumption, and dimensional accuracy.

As regarding the printing time, the analysis returned the infill type ($p = 0.002$) and infill percentage ($p = 0.008$) significantly impact printing time. Gyroid infill takes longer than rectilinear infill pattern. In the case of material consumptions, both infill type ($p = 0.001$) and infill percentage ($p = 0.0001$) significantly influence material usage. Gyroid patterns consume more material than rectilinear.

ANOVA results show the significance of infill type and infill percentage on different parameters. A p-value less than 0.05 indicates a statistically significant effect.

Tables 1 and 2 are the results of the factorial ANOVA performed in MATLAB, analyzing how infill type and infill percentage affect printing time and material consumption in 3D printing and the wall thickness.

Table 1

ANOVA for Printing Time and Material Consumption

Factor	Printing Time	Material Consumption	Interaction Effect
Infill Type	Significant	Significant	Not significant
Infill Percentage	Significant	Significant	Not significant
Interaction	Not significant	Not significant	Not significant

Table 2

Factorial ANOVA summary results.

Performance metric	Infill type	Infill percentage	Interaction
Wall thickness	Significant	Significant	Not significant
Cylinder diameter (10 mm, 5mm)	Significant	Not significant	Not significant
Hole Diameter (10mm, 5mm)	Significant	Not significant	Not significant

To quantify the effects of infill parameters, regression models were developed.

In case of printing time model, the gyroid pattern increases the print time by 3.2 min. Each 1% increase in infill adds 0.45 min. and $R^2 = 0.85$, indicating strong predictive accuracy.

For material consumption model, the gyroid pattern uses 5.4g more material. Each 1% increase in infill adds 1.8g and $R^2 = 0.92$, suggesting a robust model.

Boxplots illustrated performance variations across infill levels, confirming statistical results (Fig. 7 and 8).

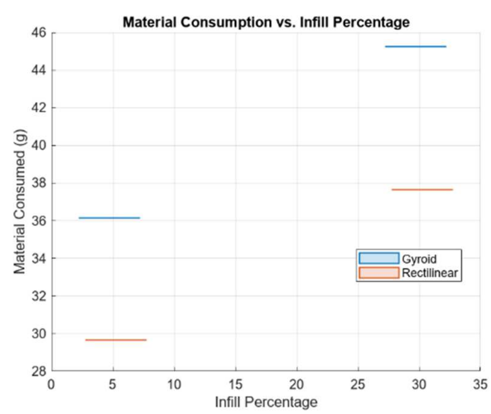

Fig. 7. Box plot for material consumption.

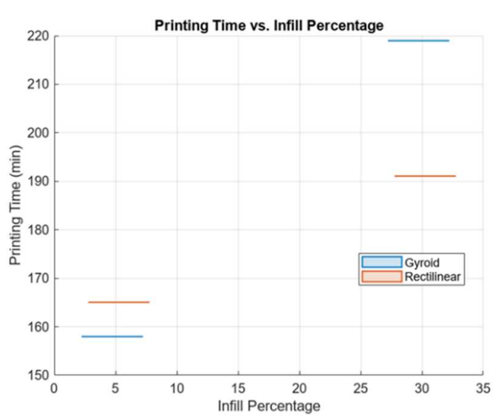

Fig. 8. Box plot for printing time.

Pareto optimization is used to identify the optimal balance between minimizing printing time and material consumption (Fig. 9).

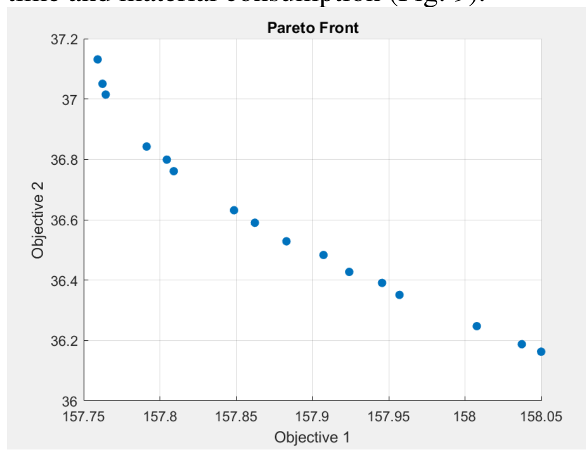

Fig. 9. The Pareto-optimal solutions.

For evaluating the effects of infill type and percentage on the printing time and material consumption, contour plots were generated. Contour plots provided a visual representation of the relationship between infill percentage, printing time, and material consumption, illustrating that lower infill percentages enhance both efficiency and resource utilization (figures 10 and 11). On X-axis is the infill percentage while on Y-axis the infill type (0 = Rectilinear, 1 = Gyroid). Contour plots help visualize optimal settings by displaying how these variables interact in a 2D space.

To visually represent the conducted investigation, the flowchart in Figure 11 was created using the specialized software Microsoft Visio.

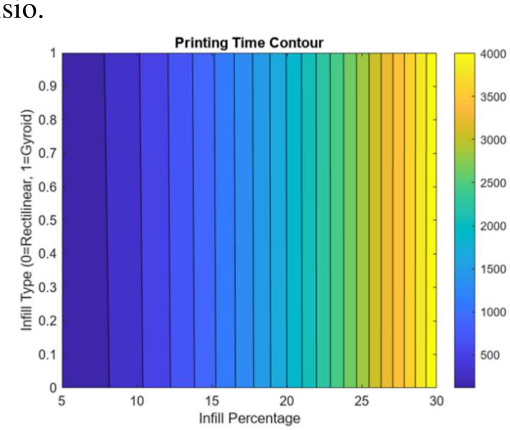

Fig. 10. Contour plot for Printing Time.

The flow chart of the entire analysis is presented in Figure 12.

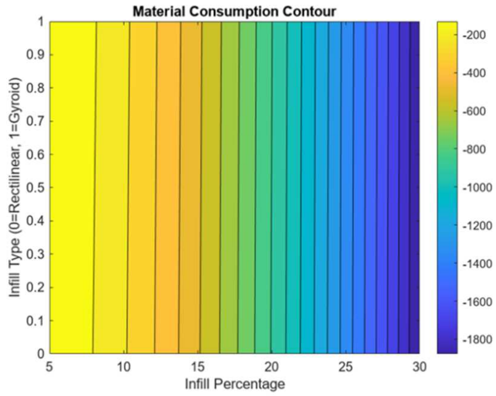

Fig. 11. Contour plot for material consumption**.**

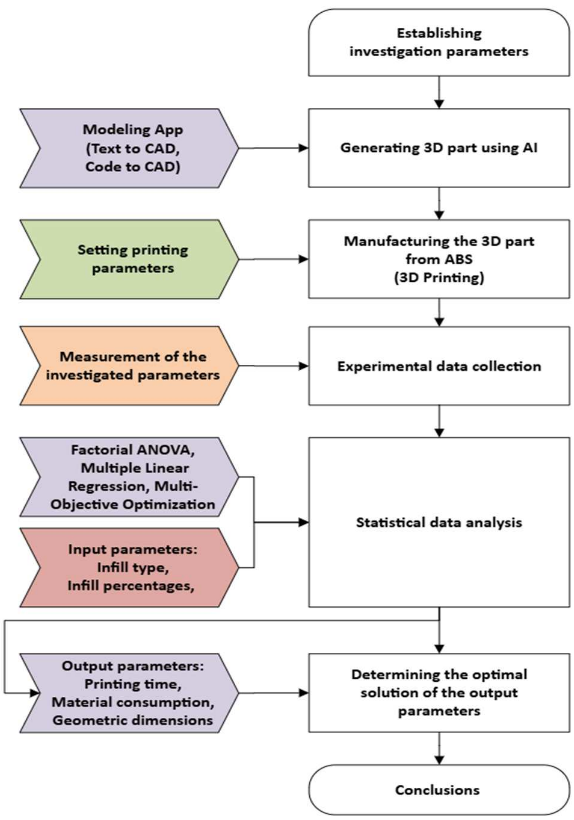

Fig. 12. Flow chart of the analysis process.

5. CONCLUSIONS

The factorial analysis allowed us to study multiple factors and their interactions in a single experiment, saving time and resources compared to conducting separate experiments for each factor.

This study demonstrates that statistical analysis, combined with CAD automation, is an effective tool for optimizing additive manufacturing parameters.

ANOVA and regression modeling offer valuable insights, enabling manufacturers to optimize 3D printing efficiency by evaluating measurable performance factors.

The integration of text-based and code-based CAD generation tools ensures a flexible and reproducible approach to design, enhancing the effectiveness of 3D printing processes. Future work will focus on integrating machine learning algorithms to refine predictive capabilities further.

This analysis suggests that selecting a rectilinear infill pattern and lower infill percentages is an effective strategy for reducing printing time.

For minimizing material usage, rectilinear infill is preferable, keeping infill percentage low.

To achieve an optimal balance between speed and efficiency, Pareto optimization is utilized. Moderate infill levels reduce dimensional inaccuracies, and it leads to ensuring good print quality.

Leveraging CAD Tools by combining text-based and code-based modeling for adaptable, efficient part generation is another advantage for enhanced manufacturing process.

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Studiu asupra pieselor ABS imprimate 3D generate de AI: influența tipului de umplere și a procentului utilizând ANOVA factorială, regresie și optimizare multi-obiectiv

Acest studiu prezintă o analiză factorială cuprinzătoare și o abordare bazată pe ANOVA pentru optimizarea eficienței imprimării 3D prin investigarea impactului tipului de umplere și al procentului de umplere asupra timpului de imprimare și a consumului de material. Cercetarea integrează instrumente AI de generare CAD bazate pe text și cod pentru proiectarea piesei imprimate 3D, urmată de evaluare statistică folosind MATLAB. Rezultatele oferă informații utile în echilibrarea vitezei de imprimare și a utilizării materialelor, sporind eficiența producției aditive. Materialul folosit pentru piesele imprimate investigate este ABS.

Cuvinte cheie: *imprimare 3D, automatizare CAD,* ANOVA, *regresie liniară multiplă, optimizare.*

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