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RESEARCH ON THE IMPACT OF 3D MODEL PREPARATION TOOLS ON THE QUALITY OF 3D PRINTING FOR PROMOTIONAL AND SOUVENIR PRODUCTS

The study investigates the influence of software tools for preparing 3D models of promotional and souvenir product elements for 3D printing using FDM technology on the accuracy of their dimensional characteristics. The experimental 3D printing process was carried out using identical configuration parameters of Slicer Software, and the results were analyzed in the context of comparing deviations in the dimensional characteristics of the 3D models and the printed elements of promotional and souvenir products.

The experiment determined that all types of software from the Slicer Software group ensure the transformation of 3D models for 3D printing. As a result, the deviations in the dimensional characteristics of the printed 3D elements of promotional and souvenir products fall within acceptable limits, ensuring high-quality reproduction of CAD models.

Keywords: promotional and souvenir products; additive manufacturing; 3D printing; reproduction accuracy; dimensional characteristics; wear resistance; print quality; CAD model.

Introduction

In the modern era of rapid development of additive technologies in the printing market, the issue of ensuring high-quality final printed products has gained significant attention. One of the key aspects is the accuracy of reproducing the dimensional characteristics of 3D products, which depends not only on the equipment but also on the process of preparing 3D models for printing. At this stage, software for model preparation plays a crucial role, as it transforms 3D models into layers suitable for printing.

Examples of printing products incorporating additive technologies include: volumetric promotional brochures or catalogs with integrated 3D-printed components to showcase products or services; premium-class souvenir packaging, where 3D printing is used to create unique decorative or functional elements integrated into the printed box; and three-dimensional signs or plaques produced using additive methods with printed graphic elements [1]. In such products, the accuracy of preparing 3D models is critical, as deviations in dimensional characteristics or software compatibility issues may complicate the integration of 3D-printed parts with printed elements, negatively impacting the quality, functionality, and appearance of the final product.

The advantages of additive manufacturing, such as reduced material waste, environmental sustainability and recyclability, process optimization, digitalization, and the accessibility of modeling processes, make additive technologies well-suited for industrial use [2].

The FDM (Fused Deposition Modeling) technology involves layer-by-layer extrusion of consumable material through the nozzle of 3D equipment, replicating the cross-section of the 3D object to form its geometry [3]. To ensure the quality of 3D products created with FDM technology in accordance with additive manufacturing quality standards [4], and to optimize the printing process, various factors and their impacts must be considered [5]. One of the primary requirements for achieving high-quality 3D products with FDM is the accuracy in reproducing the dimensional characteristics of the printed 3D object as compared to its CAD model [6].

A critical stage in the pre-print preparation process for 3D printing is the conversion of the CAD model into G-code. This step enables the model to be divided into thin horizontal layers, ensures control over object orientation, generates support structures, determines extrusion speed and temperature, and optimizes the movement trajectories of the printing tools [7, 8]. These tasks are carried out using specialized application software known as Slicer Software.

Currently, there is a wide range of Slicer Software tools available, including XYZware, Ultimaker Cura, and PrusaSlicer. Each of these programs employs unique algorithms that can affect the accuracy of reproducing the dimensional characteristics of 3D models.

However, the comparative analysis of the capabilities of Slicer Software tools (e.g., XYZware, Ultimaker Cura, PrusaSlicer) in terms of configuring printing parameters remains insufficiently explored. There is a lack of consolidated information on the effectiveness of these tools in optimizing printing parameters to enhance the quality of 3D products. Additionally, no clear analysis exists regarding the precision with which these programs replicate the dimensional characteristics of models. Furthermore, the use of various consumable materials necessitates consideration of their physical properties during printing, requiring precise printing parameter adjustments and accounting for the technical capabilities of the 3D equipment to ensure the strength of the final 3D product [9]. These factors complicate the selection of optimal software for printing complex designs of printed products, potentially leading to reduced product quality, increased material waste, and extended time for refinement. Given the complexity of 3D models in terms of construction, this stage demands further investigation.

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The need for comparative analysis of slicing software capabilities (XYZware, Ultimaker Cura, PrusaSlicer) becomes even more pertinent when considering specific equipment, such as the XYZprinting da Vinci Jr. 1.0 Pro 3D printer. This type of printer includes built-in slicing software, XYZware, developed specifically by the manufacturer. Using third-party software like Ultimaker Cura or PrusaSlicer may result in G-code compatibility issues, as the printer's firmware may not support advanced commands or parameters generated by these programs. This could negatively affect the accuracy of dimensional reproduction and the quality of the final product.

Therefore, it is essential to study the impact of preparing 3D models using different software tools, particularly XYZware, Ultimaker Cura, and PrusaSlicer, given their popularity in the software market. This analysis will help develop recommendations to optimize the process and improve the dimensional accuracy of the final printed products.

Objective of the Study to analyze the impact of software tools used for preparing three-dimensional models of 3D elements of promotional and souvenir products (Slicer Software) for 3D printing using FDM technology on the quality parameters of 3D printing, specifically the accuracy of reproducing their dimensional characteristics.

Methods

For the experimental research involving the creation of a CAD model, Blender 3D 3.5 software was used, and the developed models were saved in the *.STL format [10]. To transform the CAD model, transfer it to 3D printing equipment, determine the extrusion speed, optimize the printing toolpath, and control the orientation during layer formation, the following Slicer Software programs were selected: XYZware [11], Ultimaker Cura [12], and PrusaSlicer [13]. The compatibility parameters of the 3D equipment with the analyzed software tools and the key configuration parameters [14, 15] affecting the accuracy of dimensional reproduction of promotional and souvenir products are presented in Table 1.

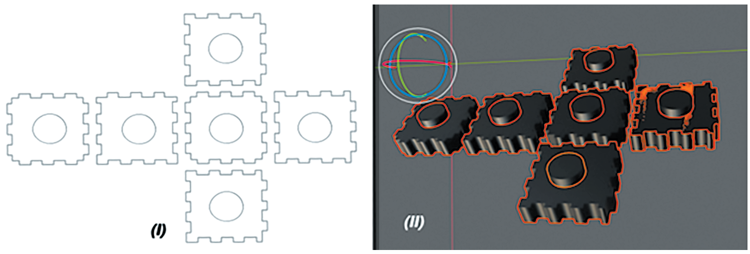
Unification of parameters for 3D printing using the studied software tools is based on setting identical values for the parameters that have the greatest impact on the quality of the printed advertising and souvenir product compared to its CAD model (Table 1). This approach enables comparative studies on the accuracy of dimensional reproduction while minimizing the influence of different settings on the 3D printing results.

At the pre-printing stage, an experimental CAD model was developed (Fig. 1) with specified dimensions: a = 102 mm, b = 15 mm, c = = 14 mm, d = 5 mm, e = 42 mm, g = = 92 mm (Fig. 2).

The printing of experimental samples was carried out using the 3D equipment XYZprinting da Vinci Jr. 1.0 Pro [16].

Existing consumables for FDM 3D printing have been analyzed, and their generalized characteristics are presented in Table 2 [17, 18].

For experimental research, PLA plastic was chosen as the consumable material. The choice was based on its minimal emission of toxic sub-



a b

Fig. 1. Elements of the experimental 3D product design at the modeling stage: a — 2D model view; b — CAD model

stances during printing, its eco-friendliness, and its compatibility with the experimental equipment [19].

Input parameters were set in the software for the experiments. Considering that high printing speeds can reduce printing accuracy, the printing was conducted at two speeds, specifically: V_1 = = 30 mm/s and V_2 = 60 mm/s. Calibration and experimental 3D models do not require high strength; instead, lightness is an important characteristic. Based on this, the following parameters were set for the research: wall thickness — 0.8 mm, infill density — 10 % [20],

Table 1

Comparative characteristics of Slicer Software configuration parameters

№	Parametr	XYZware	Ultimaker Cura	PrusaSlicer
1	Supported file formats	STL, OBJ, 3W	STL, OBJ, 3MF, X3D, BMP, GIF, JPG, PNG	STL, OBJ, AMF, 3MF
2	G-code compatibility with XYZware firmware	Complete	Complete	Complete
3	Extrusion temperature, ˚C	180–260	160–280	160–300
4	Printing speed, mm/s	10–100	10–200	10–200
5	Layer height, mm	0.1–0.4	0.06–0.4	0.05–0.35
6	Infill density, %	10–100	0–100	0–100
7	Extrusion nozzle size, mm (standard/other available sizes)	0.4/ 0.3; 0.6; 0.8	0.4/ 0.25; 0.6; 0.8	0.4/ 0.25; 0.6; 0.8
8	Infill methods	Linear, concentric	Linear, concentric, hexagonal, triangular, cubic	Linear, concentric, hexagonal, triangular, cubic
9	Market demand for Slicer Software in 2022–2024, %	20	45	35

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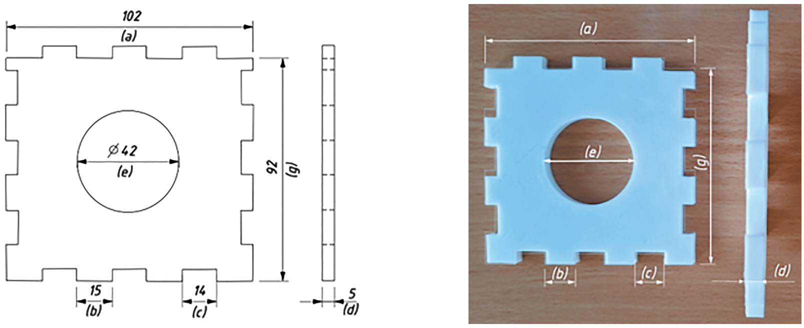

a b

Fig. 2. Experimental sample with examined linear dimensional characteristics: a — at the modeling stage; b — after the 3D printing stage

and infill method — linear. Typically, the thickness of the first bottom layer, which ensures proper adhesion to the platform of calibration 3D models, is 0.2–0.3 mm. However, considering the dimensional characteristics of the experimental 3D model and to ensure full adhesion, the thickness of the first bottom layer was increased to 1.2 mm.

Platform leveling before printing (Auto Bed Leveling), determining the number of steps of the extruder stepper motor needed to feed a certain amount of filament (E-steps/'extruder steps'), and adjusting the distance between the extruder and platform to set the height of the first printed layer (Z-offset) are integrated directly

Table 2

Comparative characteristics of consumables for FDM printing

№	Characteristic	PLA	ABS	PETG
1	Eco-friendliness	biogradable	non biogradable	
2	Styrene Emission (ppm)	< 5	20–30	< 20
3	Heat Resistance (˚ C)	55–60	80–105	70–80
4	Strength (MPa)	45–65	40–80	50–70
5	Density (g/cm^3)	1.24–1.25	1.04–1.06	1.27–1.31
6	Elastic Modulus (GPa)	3.5–7.5	1.5–3.5	1.5–2.5
7	Moisture Content (%)	< 0.3	< 0.1	< 0.1
8	Filament Diameter (mm)	1.75/2.85	1.75/2.85	1.75/2.85
9	Extrusion Temperature (˚ C)	180–220	210–250	230–250
10	Printing Speed (mm/s)	30–100	30–80	30–60
11	Layer Thickness (mm)	0.05–0.3	0.05–0.3	0.05–0.3
12	Shape Recovery (%)	70–90	60–80	70–85

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into the 3D printer, with these parameters being automatically managed.

Initially, to verify the quality of the 3D equipment (platform calibration, PLA filament behavior) and to establish unified parameters, standard calibration 3D models were printed, specifically: Calibration Cube and 3D Benchy. Six calibration models of each type were printed using each of the three studied software programs, with 3 samples printed at a speed of V_1 = = 30 mm/s and the other 3 samples at V_2 = 60 mm/s.

For the printing process, the recommended optimal parameters provided by the 3D equipment manufacturers were set: layer height (h) was 0.2 mm, infill density (I) was 10 %, infill method was linear, and extrusion temperature (t) was 220° C [21]. The total number of printed calibration samples was 18.

The accuracy of dimensional reproduction and angles was verified using a caliper SCTM 0–150 mm (accuracy ±0.01) [22] and an electronic digital protractor Elecall (accuracy ±0.2°) [23]. The summarized measurement results of the dimensional characteristics of the calibration samples are presented in Table 3.

No critical deviations were found in the dimensional characteristics or issues with the operation of the 3D equipment and PLA materials used during the printing of calibration samples. Therefore, the parameters set for the Slicer Software during the printing of calibration samples can be applied to the production of experimental samples.

For the main experiments, 12 experimental 3D products were printed for each of the three Slicer Software programs under investigation: 6 samples were printed at a printing speed of 30 mm/s, and the other 6 samples were printed at 60 mm/s (Figures 3, 4). The total number of experimental samples was 36. The number of experimental samples was determined by the overall design of the 3D product (Figure 1). The complete design involves 6 elements, each with a different

Table 3

Summarized results of measurements for calibration model printing

Parametrs	Calibration Cube	3D Benchy	Compliance with the standard [25]
Dimensional accuracy, mm: 1. at V_1 = 30 mm/s: X_1 / Y_1 / Z_1 2. at V_2 = 60 mm/s: X_2 / Y_2 / Z_2	X_1: 20.02 / Y_1: 19.98 / Z_1: 20.03 X_2: 20.05 / Y_2: 19.95 / Z_2: 20.07	X_1: 60.01 / Y_1: 31.99 / Z_1: 48.98 X_2: 60.08 / Y_2: 32.03 / Z_2: 49.05	Complies (±0.1 mm)
Overhang (45°)	No defects	No defects	Complies
Bridges (10 mm)	No sagging	No sagging	Complies
Angle accuracy (90°)	89.8°	89.8°	Complies (±0.2°)

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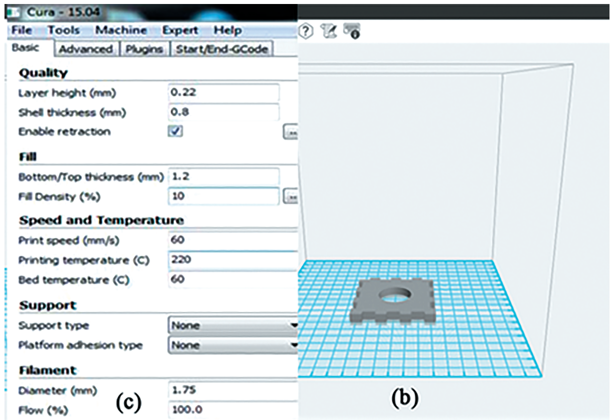

Fig. 3. Used 3D printing parameters for Slicer Software (using Ultimaker Cura (c) as an example) for experimental samples ‘sorter’ (b)

groove placement. The absence of one of the elements prevents further use of the promotional 3D product.

The basic printing parameters for 3D printing [24] for all the investigated Slicer Software programs are shown using Ultimaker Cura as an example in Figure 3. The extended parameter settings are presented in Table 4.

During the experimental research, it was found that the choice of Slicer Software significantly affects the reproduction of linear

Table 4

Input configuration parameters of Slicer Software during printing on the XYZwareing da Vinci 1.0 PRO 3D printer

Configuration Parameter	Slicer Software: XYZware, Ultimaker Cura, PrusaSlicer
Type of material	PLA
PLA filament diameter	1.75 mm
Layer height	0.2 mm
Wall thickness	0.8
Extruder nozzle size	0.4
Fill: bottom/top thickness	1.2
Fill density	10 %
Fill method	liniar
Print speed	30–60 mm/s
Extrusion temperature	220° C
Support structures	no
Process compensation	100 %

dimensional characteristics of 3D products. Therefore, the key parameters of the study were selected based on the accuracy of dimensional characteristics reproduction, depending on the Slicer Software used in comparison with the CAD model. Each CAD model is marked with a specific color (Fig. 4), corresponding to the chosen type of Slicer Software used during the printing process.

The basis for estimating geometric linear deviations was the least squares method (LSM), the linear approximation equations were found for each of the software groups (XYZware (1), Ultimaker Cura (2), PrusaSlicer (3)), and the graph of the approximation results was used for visualization.

$$y_{(XYZware)} = 0.9967x - 0.1085 \quad (1)$$

$$y_{(Ultimaker\ Cura)} = 1.0014x - 0.0883 \quad (2)$$

$$y_{(PrusaSlicer)} = 1.0001x - 0.1364 \quad (3)$$

Results

Critical measurement points for the dimensional characteristics of 3D products were identified (Fig. 2). Their selection is based on the fact that significant deviations in dimensional characteristics between the CAD model and the printed parts of the 3D products make it impossible to assemble the product's full structure, and subsequently, to use it for its intended purpose. The summarized results of the research for all Slicer Software are presented in Table 5.

A detailed analysis of the obtained values (Table 3) indicates that the dimensional deviations between the CAD models and the values of printed promotional souvenir 3D items from (a) to (g) (Table 5) range from 0.01 to 0.40 mm (up to 2.20 %) at V_1 = 30 mm/s, and from 0.03 to 0.41 mm (up to 2.63 %) with V_2 = = 60 mm/s settings.

Discussion

According to the classification of tolerances [25], depending on the printing technology, the dimensional characteristics of printed 3D items and CAD models with dimensions of length/width/height ranging from 50 to 200 mm and thickness from 5 to 20 mm, the permissible dimensional deviations are in the range of 0.2–0.5 mm, and are divided into accuracy classes: 'fine' (Fine, f) – 0.1–0.15 mm, 'medium' (Medium, m) — 0.2–0.3 mm, 'coarse' (Coarse, c) — over 0.5 mm.

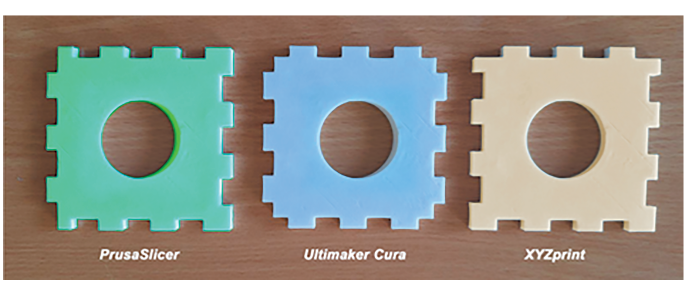

Fig. 4. Experimental samples of the CAD model 'sorter' after the 3D printing stage using the studied Slicer Software

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The obtained dimensional deviations for all investigated Slicer Software belong to the accuracy classes: 'fine' (Fine, f) — 0.1–0.15 mm and 'medium' (Medium, m) — 0.2–0.3 mm, both at V_1 = 30 mm/s and V_2 = 60 mm/s. This indicates that there were no critical deviations from the planned parameters of the Slicer Software, and pre-printing optimization of the CAD models contributed to the results. The smallest dimensional deviation values between CAD models and the printed 3D items — up to 3.28 % — were observed when using the Slicer Software Ultimaker Cura at V_1 = 30 mm/s. This allows Ultimaker Cura to be determined as the optimal software for manufacturing 3D elements for promotional-souvenir products using additive technologies.

Conclusions

The results of the research provide grounds to claim that the experimental Slicer Software, namely XYZware, Ultimaker Cura, and PrusaSlicer, allow the process of slicing the 3D model into layers and setting the printing parame-

Table 5

Summarized results of the measurement of dimensional characteristics of printed 3D products

Index	Slicer Software	XYZware			Ultimaker Cura			PrusaSlicer		
	CAD-model, mm	Absolute value	Deviation	Percentage part	Absolute value	Deviation	Percentage part	Absolute value	Deviation	Percentage part
		mm	mm	%	mm	mm	%	mm	mm	%
Print velocity, V_1 = 30 mm/s										
(a)	102	102.16	0.16	3.2	102.11	0.11	2.18	102.11	0.11	2.20
(b)	15	14.66	0.34	2.27	14.89	0.11	0.67	14.79	0.21	1.40
(c)	14	14.09	0.09	0.64	14.02	0.02	0.14	14.04	0.04	0.29
(d)	92	91.60	0.40	0.45	92.02	0.02	0.02	91.69	0.31	0.34
(e)	42	41.68	0.32	0.76	41.82	0.18	0.43	41.70	0.30	0.71
(g)	5	4.89	0.11	2.20	4.99	0.01	0.20	4.95	0.05	1.30
Print velocity, V_2 = 60 mm/s										
(a)	102	101.59	0.41	0.6	102.12	0.12	2.54	102.13	0.13	2.56
(b)	15	14.64	0.36	2.43	14.87	0.13	0.87	14.77	0.23	1.53
(c)	14	14.11	0.11	0.78	14.03	0.03	0.21	14.05	0.05	0.35
(d)	92	91.59	0.41	0.46	92.03	0.03	0.03	91.66	0.34	0.36
(e)	42	41.67	0.33	0.78	41.80	0.20	0.48	41.68	0.32	0.76
(g)	5	4.87	0.13	2.63	4.99	0.01	0.22	4.92	0.08	1.60

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ters according to the FDM technology. As a result, the dimensional deviations of the manufactured 3D elements for promotional-souvenir products are within acceptable values, ensuring the accuracy and quality of the reproduction of CAD models.

The smallest dimensional deviations between CAD models and the printed 3D parts were recorded when using the Slicer Software Ultimaker Cura, both at V_1 = 30 mm/s and V_2 = 60 mm/s. This demonstrates the effectiveness of the data processing algorithms, the reliability of the software under varying printing conditions, and the ability to optimize them. This contributes to the predictability of printing results, reduces the need for post-processing of printed 3D items, and highlights the high level of integration of Ultimaker Cura with the hardware of 3D printers. This, in turn, enables maximum synchronization between software control and the physical printing process, ensuring the accuracy and quality of the products.

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Досліджено вплив програмних засобів підготовки тривимірних моделей елементів рекламно-сувенірної продукції для 3D друку за технологією FDM на точність відтворення їх розмірних характеристик.

Ключові слова: рекламно-сувенірна продукція; адитивне виробництво; 3D друк; точність відтворення; розмірні характеристики; зносостійкість; якість друку; CAD-модель.

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