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Influence of 3D printing technology on reproducing cultural objects in the context of visually impaired people

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ABSTRACT

The number of people with vision impairments is steadily increasing, emphasizing the need to prevent their exclusion from all spheres of public life, including cultural access. This research investigates the influence of 3D printing technologies on reproducing cultural objects to enhance accessibility for visually impaired individuals. The study focuses on evaluating various 3D printing methods (FDM, mSLA), print layer heights, and materials. Significant findings indicate that while mSLA is preferred for highly detailed objects, FDM suffices for simpler objects due to its cost-effectiveness and accessibility. Layer height and material choice, although impactful, are secondary to the overall tactile experience. Experimental materials showed varying degrees of effectiveness, with some failing to meet expectations. The obtained results, supplemented by findings from other studies conducted within the project, will inform the development of guidelines and best practices for adapting cultural exhibitions and museums to meet the needs of visually impaired individuals. 3D printing can significantly improve accessibility to culture for visually impaired people through replicas, Braille description plates, mock-ups, and building plans. However, to genuinely enhance the situation for blind and vision impaired people, parallel actions in other areas are also necessary, e.g. qualified personnel, audio guides, mobile applications, building adaptations, and effective spatial organization.

Keywords: 3D printing, accessibility, museum, visually impaired people.

INTRODUCTION

The number of people with vision impairments worldwide is increasing year by year. It is estimated that in 2019, there were at least 2.2 billion [1]. Among them, over 40 million are blind, and 300 million have moderate to severe vision impairments. Approximately 55% of the total in each group are female [2].

A very important issue is preventing the exclusion of such people in all spheres of public life, including access to culture. The lack of adaptation of cultural facilities for people with vision impairments is a serious problem. The vast majority of museums are not adequately equipped for blind and visually impaired people. Deficiencies can be identified in almost all areas: technical adaptation, staff qualifications, museum rooms labelling, and communication. The most significant issue is the lack of opportunity to experience artworks through touch [3–6]. These conclusions can also be confirmed by survey research conducted by the authors. Most respondents either do not attend exhibitions at all or do so less than once a year. Improvements related to exhibitions and the artworks themselves, such as qualified guides, tactile maps, mock-ups, audio descriptions, objects replicas, and Braille descriptions, are still not standard practice and often only pertain to parts of exhibitions.

Developing 3D printing technology can be used to address most of the issues presented above. These include mainly preparing of replicas of objects, mock-ups, and plates with descriptions in Braille. Research is currently being conducted worldwide on the possibilities of using object digitization methods and 3D printing to improve access to cultural objects for people with visual impairments. A large part of the research conducted was purely qualitative and concerned the basic issues and perceptions of blind and visually impaired individuals regarding the perception of objects and replicas of artworks [3, 6, 7]. Other research was also conducted on the significance of tactile images in the education of blind students [8]. Some studies focused on conducting a series of experimental tests on a specific object (case study) to determine the best parameters for the technology used to print the object [9,10]. Issues related to the preparation of the geometric model of the object are also very important. To this end, the development of digitization methods and image processing techniques is necessary [11–13], especially in the context of objects with surfaces difficult to scan [14]. An analysis of available studies has demonstrated a significant potential in the use of object digitization methods and 3D printing to enhance the accessibility of culture for blind and visually impaired individuals. However, several important issues and challenges have been identified that require further in-depth research, such as the lack of standardization in creating replicas of museum objects [15], difficulty in developing universal solutions due to the fact that the group of people with visual impairments is very diverse [7]. However, it should be emphasized that in all studies conducted with blind and visually impaired people using printed replicas, users highlighted the ability to touch the objects as a key advantage. The benefits of printing technology in the context of replicating cultural objects include: fairly high accuracy in detail reproduction, adequate durability, pleasant tactile quality, relatively short preparation time for replicas, mock-ups, or tactile maps [9].

Parallel research is being conducted on other systems designed to assist people with visual impairments – such as audio description, navigation systems, tactile maps, descriptions in Braille [16–18]. New concepts for assistive devices are also being developed, such as a graphical Braille display. [19]. Taking all these aspects into account simultaneously will help reduce limitations and facilitate access to cultural objects for blind and visually impaired individuals in the future [20–22]. Furthermore, it should be mentioned that previous research related to the use of 3D printing in the context of replicating cultural objects is rarely comprehensive and usually focuses on only one aspect. Therefore, there is a need for studies that cover both the needs and experiences of visually impaired people and more technical issues, such as the impact of factors like technology choice, material, 3D print parameters, scale, object position, finishing.

DESCRIPTION OF THE RESEARCH

The main objective of the conducted research was to examine selected additive manufacturing technologies for various objects (replicas of sculptures, bas-reliefs, posters, architectural objects). The evaluation primarily focused on various 3D printing methods, selected printing parameters (such as layer height), and materials. It is important to note that other significant aspects were also investigated in separate studies, such as scale, object position, surface finishes, and comparison with subtractive manufacturing techniques. During the survey research, the experiences, expectations, and needs of visually impaired individuals in the context of access to museums and other cultural sites were also identified.

The entire research cycle included 20 test stands. This study is limited to research and conclusions related to the selection:

- printing technology (FDM - Fused Deposition Modelling, mSLA – Masked Stereolithography); test stands: boar, poster, building, facade.
- layer height (for FDM technology); test stands: bust 1, words in Braille.
- basic materials (for FDM technology); bas-relief figure test stand.
- experimental materials (for FDM technology); bust 2 test stand.

In the conducted research concerning the analysis of specific issues, a group of at least 10 severe visually impaired or blind people (10–14 participants) participated at each research station. All participants in the study were between 18 and 40 years old, with the group evenly divided between males and females. They were all residents of large cities. During the study, no personal data or health-related data were collected or processed. Only opinions and feelings regarding the examined objects were analyzed.

Comparison of FDM and mSLA methods

The first research cycle focused on determining the preferred method for creating objects using 3D printing technology. The methods considered were FDM and mSLA. 13 participants took part in this research step. The printed models that were tested to compare printing technologies are shown in Figures 1–3.

The most important parameters such as: technologies, layer height, materials and model size regarding the this part of the research are presented in Table 1. The participants were asked to answer the question which model (in which type of technology) they preferred. The answers are presented in Figure 4. Based on the results, it can be concluded that FDM was clearly the preferred technology for the building, while mSLA gained the upper hand for the poster. In the case of the boar, a slight advantage for FDM can be seen, while for the facade, both technologies were evaluated similarly.

From the research conducted on the choice of preferred manufacturing technology using additive manufacturing, it can be concluded that the quality of reproduction is important, but not the most important. Respondents tended to

a) b)

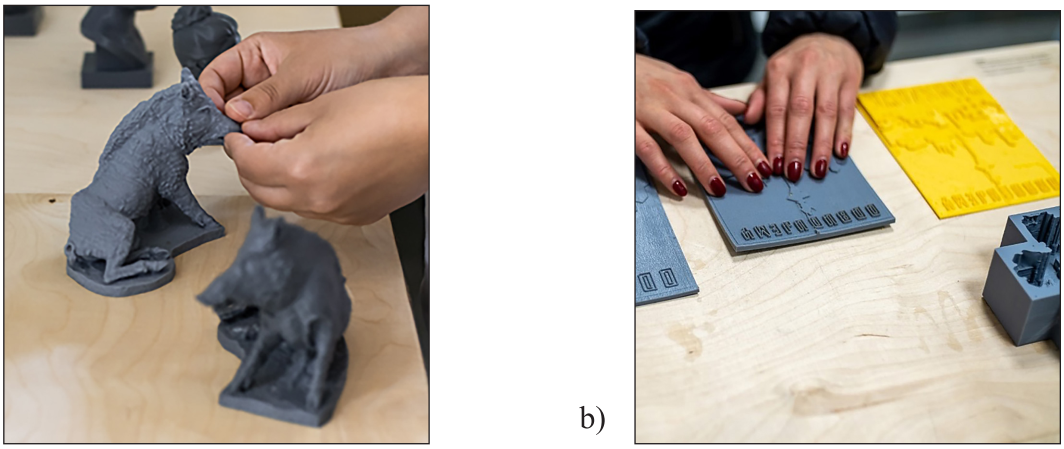

Figure 1. Test stands with: a) boar (left/grey – mSLA, right/dark grey – FDM, modificated 3D model based on: [23], b) poster (left/grey – mSLA, right/yellow – FDM, own 3D model based on graphics:[24])

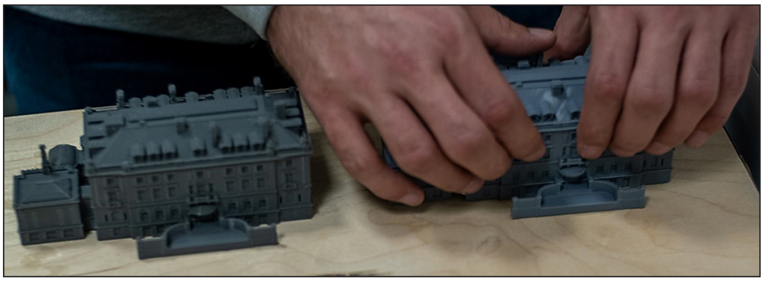

Figure 2. Test stand with building (left/dark grey – FDM, right/grey – mSLA, source of 3D model: [25])

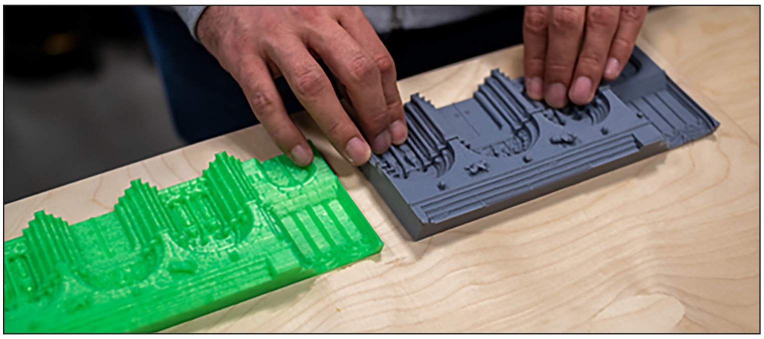

Figure 3. Test stand with facade (left/green – FDM, right/grey – mSLA, source of 3D model:[26])

Table 1. The most important parameters for test stands: boar, poster, building facade

Test stand	Boar	Poster	Building	Facade
Technology/ies	FDM mSLA	FDM mSLA	FDM mSLA	FDM mSLA
Layer height	FDM – 0.2 mm mSLA – 0.05 mm	FDM – 0.2 mm mSLA – 0.05 mm	FDM – 0.2 mm mSLA – 0.05 mm	FDM – 0.2 mm mSLA – 0.05 mm
Materials	FDM – PLA (polylactic acid) filament mSLA – Phrozen Aqua Gray 4K resin	FDM – PLA filament mSLA – Phrozen Aqua Gray 4K resin	FDM – PLA filament mSLA – Phrozen Aqua Gray 4K resin	FDM – PLA filament mSLA – Phrozen Aqua Gray 4K resin
Size	height: 150 mm	150 × 110 × 8 mm	150 × 98 × 62 mm	220 × 104 × 28 mm

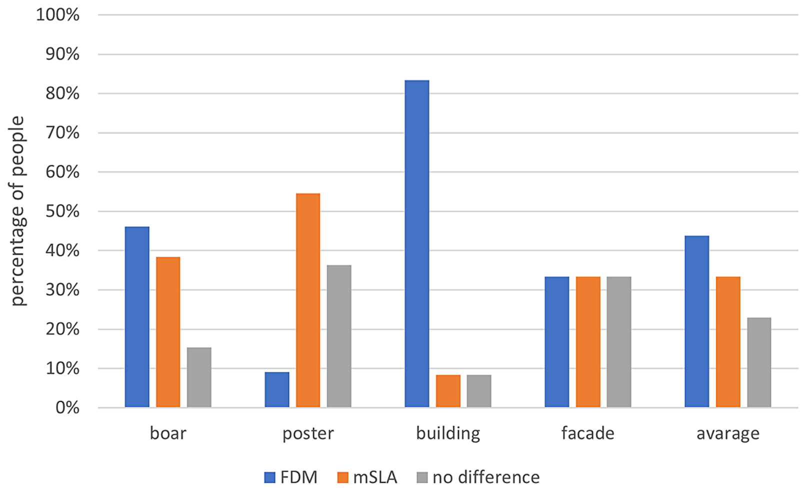

Figure 4. Results of selecting the preferred technology

sense differences between objects produced using FDM and mSLA technology, but in most cases the differences were not significant in perception. When rendering very detailed objects, the mSLA method gained the advantage. For relatively simple objects, due to the low cost, the use of FDM technology is sufficient. For some cases, the less ideal and less smooth surface texture obtained with FDM was even preferred by the participants.

It is worth mentioning that for FDM technology, PLA material was used (layer thickness of 0.2 mm, while mSLA used Phrozen Aqua Gray 4K resin (layer thickness of 0.05 mm). Thus, it should be taken into account that respondents' feelings may also have been partially influenced by these issues. Nevertheless, it should be emphasized that the chosen materials and printing parameters were typical of the technology.

Analysis of the impact of layer height

The next part of the research focused on determining the impact of print layer height on its quality (participants' perceptions). 12 people participated in case of the Bust 1 stand and 10 people for the Words in Braille station. The printed models that were tested to compare the influence of layer height are shown in Figure 5. The most important parameters regarding the this part of the research are presented in Table 2. The participants were asked to rate models considering layer height. For each model they had the opportunity to assign their rating: worst, no difference, best. The answers are presented in Figure 6 – for test stand Bust 1 and in Figure 7 – for test stand Words in Braille. The results of this experiment are not conclusive. The ranking score does not depend (e.g., in a linear way) on the selected layer height. The reasons for this result may be as follows:

- layer height has no significant effect on the resulting effect of the 3D print. The respondent's assessment of the print structure may be more influenced by other issues, and the printing process itself is largely random;
- respondents did not feel much difference, and gave an answer that was their subjective, individual feeling.

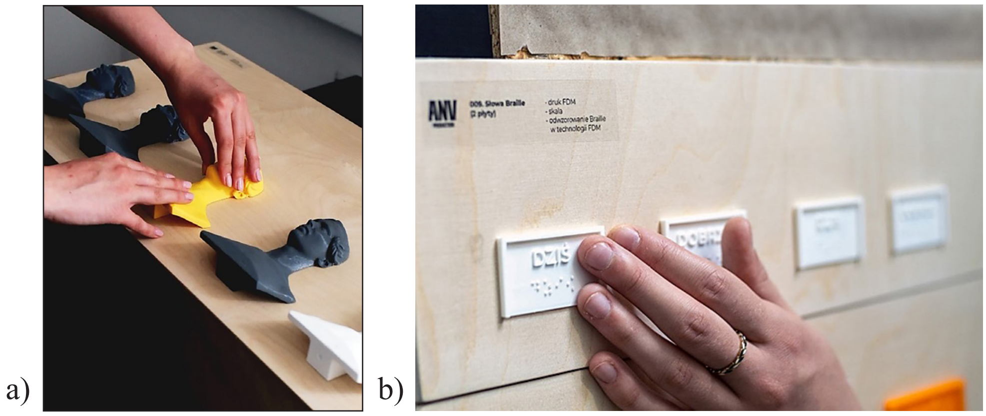

Figure 5. Test stands with: (a) bust (source of 3D model: [27]), (b) words in Braille (own 3D models)

Table 2. The most important parameters for test stands: bust 1, words in Braille

Test stand	Bust 1	Words in Braille
Technology	FDM	FDM
Layer height	0.12 mm 0.16 mm 0.20 mm 0.24 mm 0.28 mm	0.12 mm 0.16 mm 0.28 mm
Materials	PLA filament	PLA filament
Size	Lenght: 150 mm	Plate – 52 × 29 mm Text size – 5.5 mm Braille text size – according to ISO 17049 standard [28]

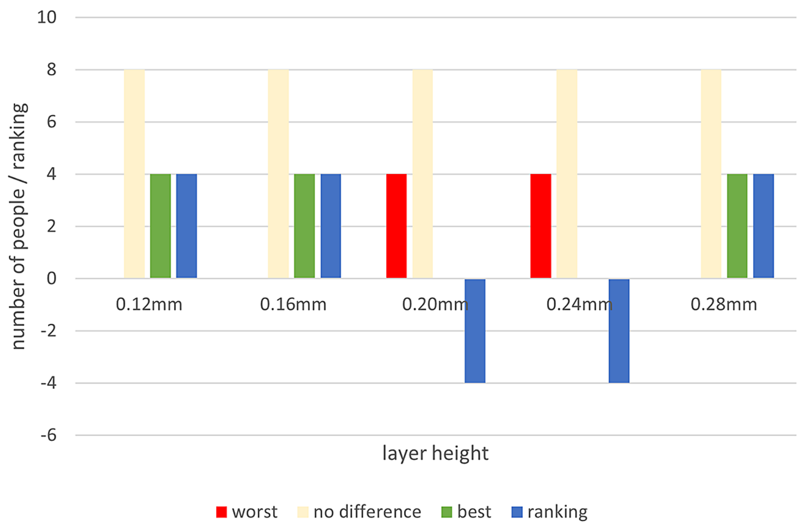

Figure 6. Results of evaluating the impact of layer height (test stand – Bust 1)

However, as a result of this experience, it is not possible to draw too far-reaching conclusions in the form that the layer height does not affect the structure of the print at all. It should be taken into account the choice of layer may be more important when mapping (printing) other types of structures (with other shapes and other detail). To determine the effect of layer thickness on the quality of 3D printing, the research continued with the example of plates with words. The words on the plates were written in both Latin and Braille (both in Polish). The results of the experiment are shown in Figure 7. In this case, the participants assessed that a layer height of 0.28 mm performed the worst in the application to print plates with words. The sample with a layer height of 0.16 mm got the most positive indications, Two positive indications were for 0.12 mm. In this case, it can be noted that there was a noticeable impact of the choice of printing layer height, the 0.28 mm layer proved to be too high.

Based on both experiments, it can be concluded that the optimal printing layer height is 0.16 mm and too high layer height values should be avoided when printing highly detailed objects.

Analysis of the impact of standard FDM materials choice

The next study focused on selecting the material for printing using FDM technology. The participants could choose between PET-G (polyethylene terephthalate glycol-modified), ABS (acrylonitrile butadiene styrene), and HIPS (high impact polistyrene). 14 participants took part in this research step. Worth mentioning is that all materials are safe for skin contact, with PET-G being suitable for both short and long-term contact, while ABS and HIPS are safe for short-term contact with no significant concerns for longer exposure. The printed models that were tested to compare the different standard materials (ABS, PET-G, HIPS) are shown in Figure 8.

The most important parameters regarding the this part of the research are presented in Table 3. The participants were asked to rate models considering different material. For each model they had the opportunity to assign their rating: worst, no difference, best. The answers are presented in Figure 9. For most of the participants, the choice of material did not matter much. However, it should be noted that a slight advantage was given to the last material (HIPS), ABS was the worst. It should be noted that the difference was felt only by some of the people surveyed. To sum up, it can be concluded that in this case the choice of material did not have a major impact on the quality of the print and participants feelings.

Analysis of the impact of experimental FDM materials choice

The final stage of the research involved testing experimental materials for 3D printing using the FDM method. The experimental materials were designed to imitate other types of structures and materials. 12 participants took part in this experiment. The printed models that were tested to compare the different experimental PLA materials (Red Satin, Stoneage, Stonefill, Mineral, Corkfill) are shown in Figure 10. The most important parameters regarding the this part of the research are presented in Table 4.

Respondents were asked to rate models made of different materials on a scale of 1–5. Participants

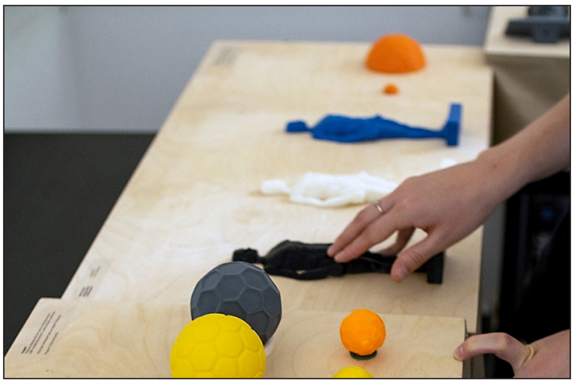

Figure 8. Test stand with bas-relief figure (modified 3D model based on: [29])

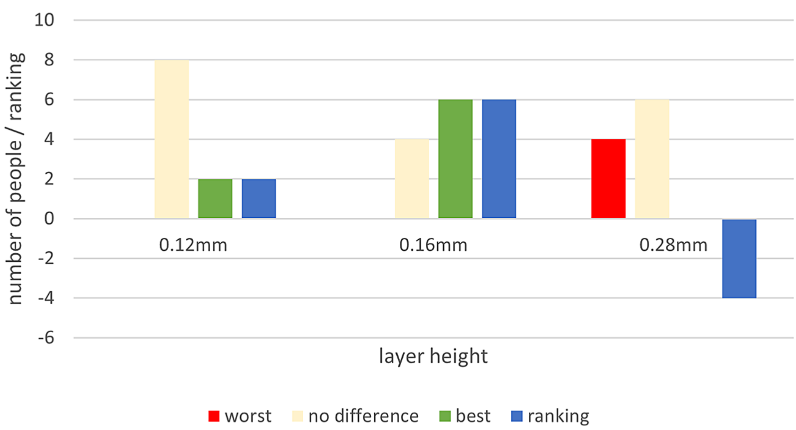

Figure 7. Results of evaluating the impact of layer height (test stand – words in Braille)

Table 3. The most important parameters for test stand bas-relief figure

Test stand	Bas-relief figure
Technology	FDM
Layer height	0.2 mm
Materials	ABS PET-G HIPS
Size	Length: 150 mm

After analyzing the experimental results, it can be seen that identifying the materials for the participants was not a simple task. For almost all cases, a large number of responses pointed to plastic or wood. Only in the case of PLA Corkfill, the separately rated the material and model fidelity. The answers are presented in Figure 11.

For this experiment, the differences were quite significant. Objects made of PLA Mineral and PLA Red Satin material were rated best, while those made of PLA Crokfill were rated worst. Models made from PLA Stonefill and PLA Stoneage performed moderately.

Participants also attempted to identify materials. Participants were not informed, so they did not need to be aware that the samples were 3D printed or of the material type used. This information was provided to them only after the experiment was completed.

Some respondents did not provide an answer, while some indicated more than one answer. It is worth pointing out that for this question there was no list of suggested answers. Multiple answers were allowed because selecting a single material could have been problematic for the respondents. The absence of a suggested list was intended to prevent any influence on the answers, which depended on the individual perceptions of the respondents. The results are shown in Figure 12.

Figure 10. Test stand with bust (source of 3D model: [27])

Table 4. The most important parameters for test stands: bas-relief figure

Test stand	Bust 2
Technology	FDM
Layer height	0.2 mm
Materials	PLA Red Satin PLA Stoneage PLA Stonefill PLA Mineral PLA Corkfill
Size	Length: 150 mm

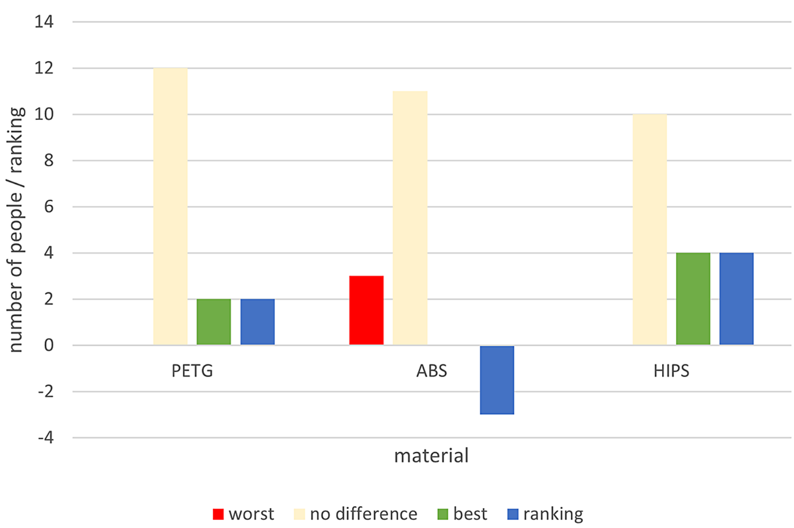

Figure 9. Results of evaluating standard materials

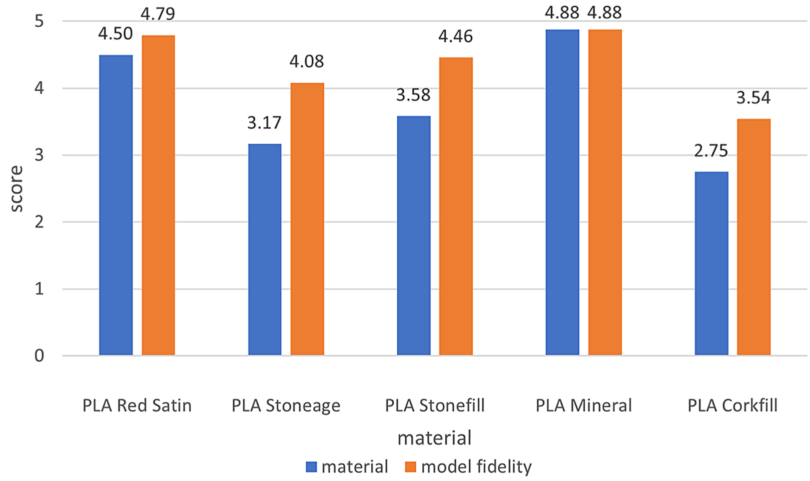

Figure 11. Results of evaluating experimental materials

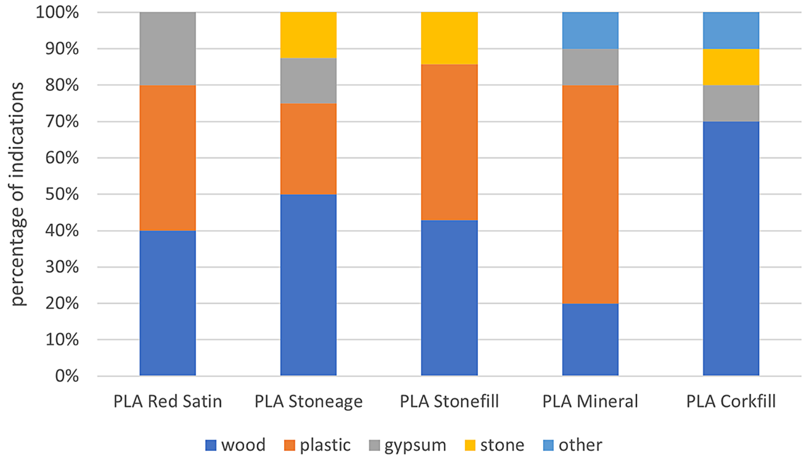

Figure 12. Results of identification of experimental materials

material was not identified as plastic by any of the respondents, while most attendees chose wood.

CONSLUSIONS

After conducting a series of studies on the issues of choosing the preferred technology of 3D printing, printing parameters (layer height), material selection, the following conclusions can be reached.

The samples prepared using 3D printing technology were received positively by the respondents. Minor defects in printed objects due to the technology itself did not interfere with them reception. After conducting research on the selection of technology, it can be concluded that this issue depends on the type of object being replicated. For objects with more complex shapes and a greater number of details (e.g., a poster), more people preferred mSLA technology. For objects such as a wild boar and a facade, the results were more balanced. However, for a building, respondents preferred FDM technology. Thus, it can be concluded that the less perfect and smooth structure obtained with FDM gains an advantage for objects with a relatively small number of details. Furthermore, it should be noted that for some people, the choice of technology was not significant. The finishing method of the object is also important. To sum up, for most objects, FDM technology, which is also cheaper and more accessible, will be entirely sufficient.

The research showed that layer height does not always significantly affect the quality of 3D prints, except in cases of objects with very high levels of detail. Specifically, for more complex structures, a smaller layer height can improve quality. In most standard applications, changes in layer height have minimal impact on the final print outcome. The participants in the study did not find the choice of material in FDM technology to be significantly impactful. HIPS showed a slight advantage over ABS and PETG. In the case of experimental materials, significant differences in evaluation were observed (PLA Mineral and PLA Red Satin were rated very highly, whereas PLA Corkfill received much lower ratings), both in terms of material assessment and model fidelity. Participants also encountered significant difficulties in identifying experimental materials. Therefore, it is advisable that for object reproduction, in most cases, standard materials should be sufficient.

In summary, after conducting a series of experiments, it can be concluded that the most important aspect is the ability to touch cultural objects. Technical issues in this case are important but secondary. The conducted research examined aspects such as the choice of technology (FDM, mSLA), print layer height settings, and material selection. Significant conclusions can be observed regarding the choice of technology - the use of technologies other than FDM should be considered only in special cases, similarly to choosing small layer height values. In terms of material selection, HIPS and PETG showed an advantage over ABS, but it was not significant. The choice of experimental materials imitating other structures often did not bring the expected results.

It is also worth noting that other studies were conducted on other very important aspects, such as the scale, position, and orientation of the object. Detailed data were also collected regarding the experiences and expectations of blind and visually impaired individuals concerning access to cultural objects. The results of these studies will help complement the existing conclusions and prepare a set of rules and best practices for adapting exhibitions and museums to the needs of visually impaired people. It should also be remembered that in order to improve the situation for these individuals, multifaceted actions should be taken in other areas as well: qualified personnel, audio guides, mobile applications, building adaptations, and good spatial organization.

The study confirms findings from the literature regarding the importance of tactile interaction for blind individuals and the potential of 3D printing for accessibility. It aligns with research on the suitability of different 3D printing technologies for cultural replicas. Unlike most prior studies, which focused on isolated aspects, this research takes a broader approach, making a significant contribution to improving accessibility to cultural objects for people with disabilities.

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