APPLICATION OF ADDITIVE MANUFACTURING TECHNOLOGIES IN THE PRODUCTION OF A MONASTERY MODEL FOR THE PRESERVATION OF SERBIA'S CULTURAL HERITAGE

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Abstract:

In order to preserve Serbia's cultural heritage and monuments that are protected as cultural assets by the state, they have been digitized in a three-dimensional electronic form. This approach ensures the creation of a permanent digital record. Monasteries and monuments in digital form can serve as the basis for the development of avatars or models within Virtual Reality systems. On the other hand, such representations are suitable for various types of presentations and educational purposes, particularly for children and tourists who are not able to physically visit or experience these sites. Technological advancements have enabled the development of virtual environments that accurately replicate real-world spaces. This paper presents a methodology that includes modeling of the Sopocani Monastery based on photographs and original architectural drawings. After the virtual model was created, a physical 3D model of the monastery was produced using FDM (Fused Deposition Modeling) additive manufacturing technology. In addition, a mold was made from silicone material, which can potentially be used to produce replicas of the monastery using different materials. This mold was used to fabricate a model of the Sopocani Monastery in epoxy resin.

Keywords:

Rapid Prototyping, Additive Manufacturing, Rapid Tooling, 3D Printing.

INTRODUCTION

Cultural heritage represents the legacy passed down from previous generations and encompasses both tangible and intangible assets that are vital for the identity and continuity of a community. It includes archaeological sites, historical buildings, works of art, as well as traditions, language, and customs that shape a nation's cultural identity. Preserving and protecting these assets is essential for transmitting values, knowledge, and traditions to future generations. The protection of cultural heritage involves various measures aimed at identifying, documenting, researching, maintaining, and promoting cultural properties. These measures ensure sustainability and accessibility, preventing deterioration, damage, or destruction caused by natural disasters, urbanization, or neglect. Furthermore, protecting cultural heritage strengthens cultural identity, encourages cultural tourism, and positively impacts the economic development of communities.

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In the modern age, technological advancements provide new opportunities for preserving and presenting cultural monuments. One innovative method is the creation of three-dimensional (3D) models of cultural assets. Developing 3D models allows for detailed digital documentation of objects, which is highly valuable for analysis, restoration, and education. The physical production of these models using 3D printers enables the creation of accurate replicas of monuments that can be used in museums, educational institutions, or for research purposes. These models facilitate interaction with cultural assets in ways that are not always possible at the original sites, thereby increasing accessibility and awareness of the significance of cultural heritage. One key technique for generating 3D models is photogrammetry. This process uses photographs of an object taken from different angles to create accurate three-dimensional models. Software packages such as Autodesk 123D Catch or Autodesk ReCap Pro convert these photographs into detailed 3D models, providing a valuable tool for documenting and analyzing an object's physical condition. This method is especially useful for documenting complex structures, allowing professionals to study and work on preserving cultural assets without requiring constant physical access to the location. The application of photogrammetric methods and 3D modeling significantly contributes to the protection and preservation of cultural heritage in Serbia. These research efforts provide valuable insights into the potential of modern technologies for documenting and restoring cultural monuments, thereby enhancing methodologies for protecting and promoting Serbia's cultural legacy. Figure 1 illustrates the application of the photogrammetric method on the monument of Commander Petar Bojovic.

Figure 1 illustrates the process of generating a 3D model of the bust of Petar Bojovic using the Autodesk 123 Catch software. This software works by uploading a series of photographs of the object, allowing it to reconstruct the environment and create a 3D model. The technique for capturing these photographs is crucial. The object should be photographed while moving in a circular path, with the camera positioned parallel to the surface on which the object stands, ensuring that the entire object is recorded. After completing the first circular pass, a second round of photographs should be taken at a 45-degree angle relative to the base, again ensuring comprehensive coverage of the object. Each pass should consist of at least 10 to 15 images. Photographs that display glare or reflections are not useful and may compromise the quality of the 3D model reconstruction. Therefore, it is advisable to take photos under cloudy conditions and to apply a matte coating to reflective surfaces if necessary. Once the set of photos is uploaded, a 3D environment is generated, which can be cleaned and edited using built-in tools to remove any unwanted elements. In the final step, a 3D model in STL format is created, making it suitable for use with any rapid prototyping software. As shown in Figure 1c, a prismatic base has been added to the lower part of the model to serve as a stand for the bust. This method is also the most cost-effective technique for 3D model reconstruction. The second technique for generating 3D objects is simpler to perform but significantly more expensive due to the necessary equipment. It involves the use of a portable handheld 3D scanner, paired with a powerful computer. This method yields a more accurate model in terms of shape and dimensions since the scanner generates a dense point cloud connected by triangles that form the external contour of the object. The output file is also in STL format, ready for direct use on additive manufacturing machines.

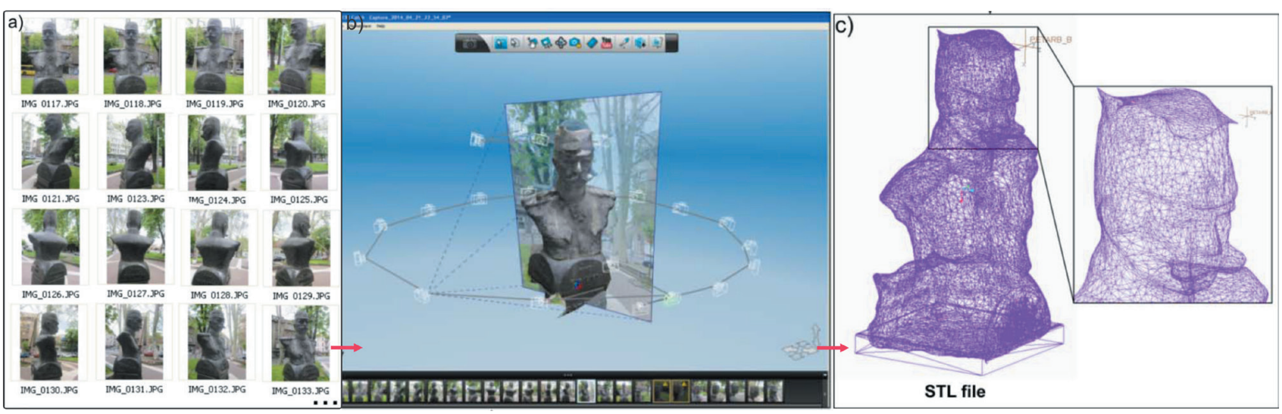

Figure 1. Photogrammetric method applied to the bust of Petar Bojovic, adapted from [3]

The third technique is the simplest and least expensive but is also the most time-consuming. It involves manual modeling using one of the available software packages, based on sketches and measurements taken on-site. This method can be seen as a form of reverse engineering of the analyzed object, allowing for a model that can be easily refined and converted into any required format for further applications. One potential use of such models is in virtual reality environments or for developing video game assets. This first chapter provides an overview of the available techniques for generating 3D objects. The second chapter will describe the specific object that will be further examined. The third chapter outlines the mold manufacturing process for producing a scale model of the object, while the fourth chapter discusses the applications of the completed mold.

2. MANUFACTURING OF A 3D MODEL OF THE SOPOCANI MONASTERY

This chapter offers an overview of the Sopocani Monastery, featuring a 3D model created using SolidWorks software. The Sopocani Monastery was constructed by King Stefan Uros (1243–1276) near the source of the Raska River, located approximately 17 km from the city of Novi Pazar. As a significant site within the medieval Serbian state of the Nemanjic dynasty, King Stefan the First-Crowned's third son left behind a legacy that, in both scale and beauty, surpassed all previous Serbian churches. The frescoes of the Sopocani Monastery are true masterpieces of artistry, and combined with its stunning architecture, they have garnered international recognition for the site. Today, the Sopocani Monastery is regarded as one of the most important cultural monuments in Serbia and has been included in the UNESCO World Heritage List since 1979, as part of the protected medieval ensemble "Stari Ras and Sopocani." [4] Figure 2 displays photographs of the Sopocani Monastery.

The photographs reveal distinct decorative elements and details along the edges of the windows and arches. While these features are quite small compared to the overall size of the monastery, they are significant. The monastery was designed to full scale, based on the documentation presented in Figure 3, which includes a properly scaled architectural drawing of the structure. A potential issue arises when manufacturing a scaled-down model of the monastery, which is 30 times smaller than the original. In this case, certain details will also

Figure 2. Photographs of the Sopocani Monastery

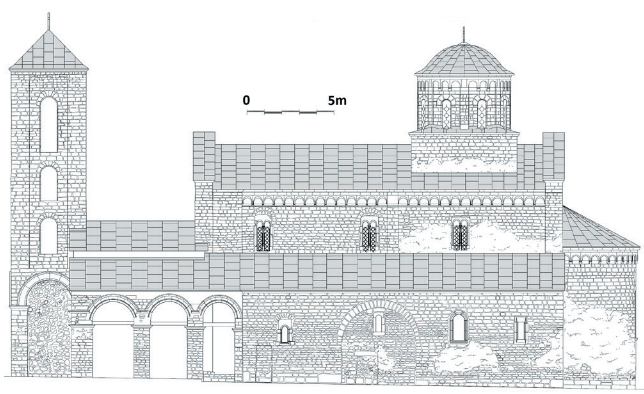

Figure 3. Documentacion of the Sopocani Monastery

be reduced by a factor of 30, potentially making them too small to be accurately reproduced. The solution is to refine the 3D model further, intentionally enlarging specific dimensions to ensure they can be effectively manufactured.

Figure 4 shows a scaled-down 3D model of the Sopocani Monastery at a scale of 30:1. It can be observed from the image that certain details, such as individual bricks or roof tiles, are not visible, simply because their dimensions affect the manufacturability of the model. Since the model of the Sopocani Monastery was manufactured using FDM (Fused Deposition Modeling) rapid prototyping technology, the gaps between bricks or the size of the tiles would influence the layer thickness during printing, and such small features would negatively impact the surface quality of the final model.

A more detailed version of the monastery model, including fine architectural elements, would be better suited for manufacturing using SLA (Stereolithography) technology a layer-by-layer additive process that is one of the oldest rapid prototyping methods. This technique is based on curing liquid polymer using a UV laser.

3. MANUFACTURING OF THE MONASTERY MODEL USING RAPID PROTOTYPING TECHNOLOGIES

This chapter will present two different available rapid prototyping technologies using the Sopocani Monastery as a case study. The first technology describes the manufacturing of the Sopocani Monastery model using FDM (Fused Deposition Modeling) rapid prototyping technology. The second technology represents the rapid production of casting tools (Rapid Tooling), which essentially uses rapid prototyping methods and silicone mixtures, rather than commercial technologies and materials, to create tools into which different materials can later be cast.

3.1. MANUFACTURING OF THE MONASTERY MODEL USING FDM TECHNOLOGY

The prepared STL file was imported into Bambu Studio software, where all key printing parameters were defined, including layer thickness, infill density, nozzle, and heated bed temperatures, as well as support structure generation.

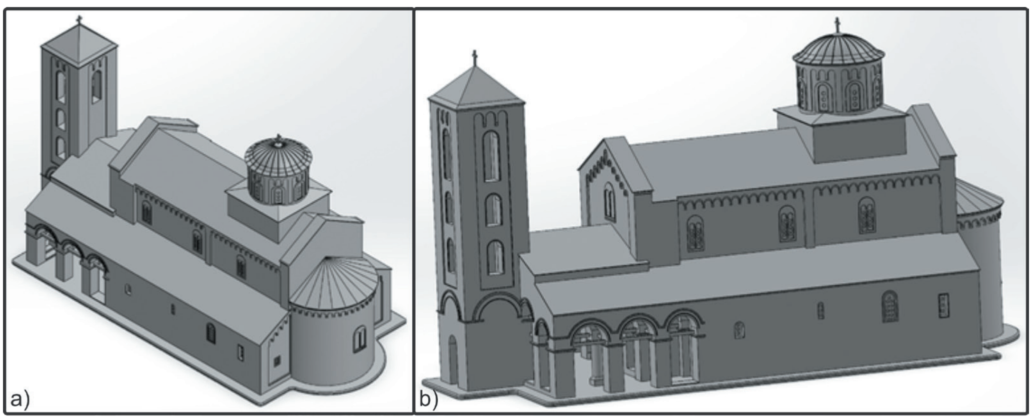

Figure 4. 3D Model of the Sopocani Monastery Created in SolidWorks Software Package

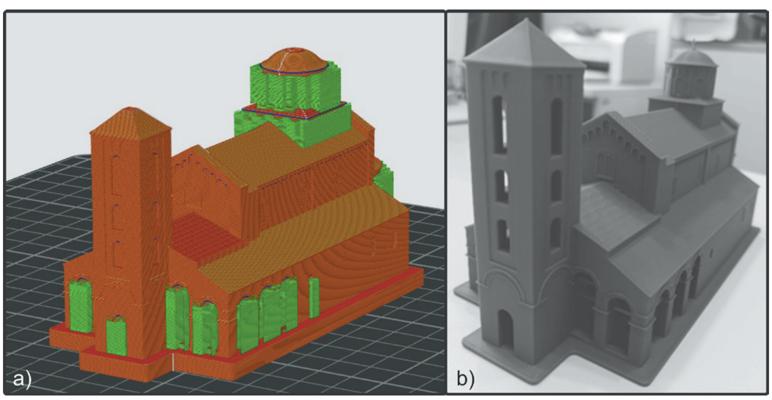

Figure 5. 3D Printed Model of the Sopocani Monastery

The model was then manufactured using the Bambu Lab P1S 3D printer, known for its high speed and precision, as well as its ability to reliably reproduce complex geometries. Figure 5a shows the preparation of the monastery model in Bambu Studio, while Figure 5b presents the printed model of the Sopocani Monastery. Upon completion of the printing process, minimal post-processing was required, consisting solely of the removal of support structures generated during printing. The support material is shown in green in Figure 5a. Thanks to the printer's precision and well-optimized parameters in Bambu Studio, additional procedures such as sanding, gluing, or painting were not necessary, which simplified and accelerated the entire manufacturing process.

3.2. MANUFACTURING OF THE MONASTERY MODEL USING RAPID TOOLING TECHNOLOGY

Rapid tooling refers to manufacturing techniques that leverage rapid prototyping technologies. In this study, rapid tooling is specifically used to create a mold for casting the model of the Sopocani Monastery. This concept involves producing a mold using a deformable silicone material, which allows for the accurate transfer of intricate details from the positive model to the negative mold. Certain geometric features of the monastery model exhibit what is known as negative geometry. If the mold were constructed from rigid materials such as metals, plaster, or sand, these features could not be removed without damaging the mold. The positive model of the Sopocani Monastery can be produced via either subtractive or additive manufacturing technologies. Since the model has already been created using Fused Deposition Modeling (FDM) technology, it is necessary to design a two-part, detachable mold that can accommodate the silicone mixture.

Figure 6 illustrates the step-by-step process of forming the silicone mold. The box that holds the monastery model was also manufactured using FDM technology and designed for easy assembly and disassembly, as shown in Figures 6a and 6b. The silicone compound used in this process is called 5.0 Premium, which consists of two components: a base material and a curing agent, mixed in a 1:1 ratio before being poured into the mold containing the positive model of the Sopocani Monastery. After one hour of curing, the outer box mold can be removed from the formed silicone mold. The final silicone mold is displayed in Figure 6c.

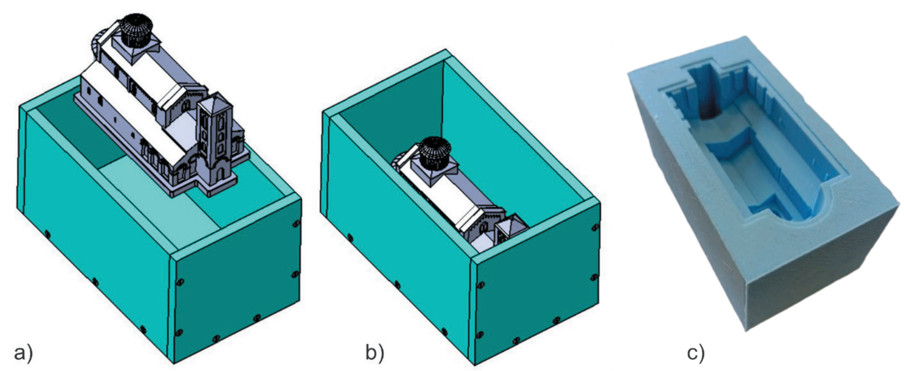

Figure 6. Silicone Mold Fabrication Process

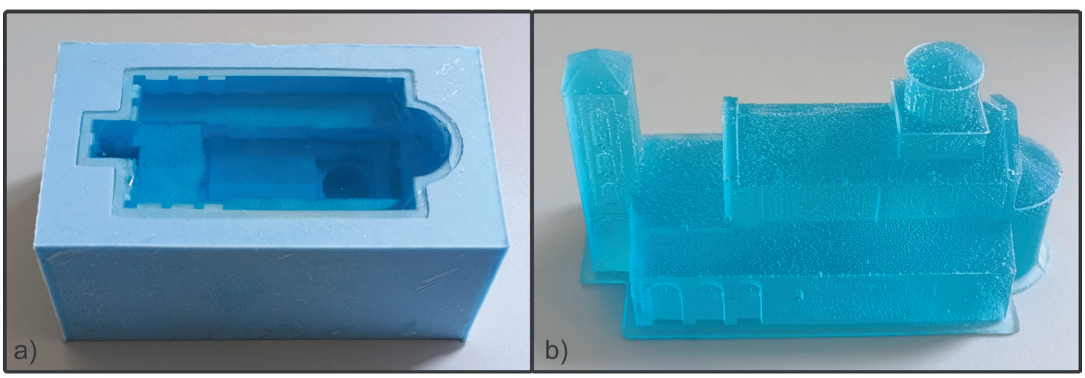

Figure 7. Process of Manufacturing the Sopocani Monastery Model Using Epoxy Resin

The resulting mold is a finished product ready for use. Various types of liquid polymers, such as two-component epoxy resin, can be poured into the mold. This epoxy resin hardens after a specific period of time. The initial curing period is 24 hours after pouring, but the material reaches its final properties after 10 days of curing. Since epoxy resin is a two-component system mixed with a hardener in a 2:1 ratio, it is essential to use a heat gun or torch during the pouring process. This is done to treat the upper surface of the cast material and eliminate any air bubbles formed during mixing. Once poured into the mold, the epoxy resin generates a certain amount of heat, which helps expel bubbles from the mixture. Figure 7a shows the epoxy resin poured into the silicone mold, while Figure 7b displays the finished scale model of the Sopocani Monastery made from epoxy resin.

4. CONCLUSION

The use of additive manufacturing technologies for preserving cultural heritage represents an innovative blend of modern engineering and cultural stewardship. This is exemplified by the production of a scale model of the Sopocani Monastery, which showcases the effectiveness of Fused Deposition Modeling (FDM) technology in creating physical representations of historically significant structures. The monastery was digitized using SolidWorks software, and then a 3D model was printed with a Bambu Lab P1S printer. This process allowed for the accurate and rapid production of a scaled-down version of the monastery, requiring minimal post-processing. Additionally, a silicone mold was created to facilitate the serial production of models, which can be made from various materials, such as epoxy resin.

This approach not only aids in the preservation of cultural heritage through documentation and education but also opens up opportunities for museum exhibits, souvenirs, and interactive educational content. The combination of digital technologies and additive manufacturing offers a wide array of applications in protecting, promoting, and educating about cultural and historical heritage, enhancing the accessibility, durability, and appeal of cultural content.

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