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Alberta Paglione, Carla Giovannone, Angelo Raffaele Rubino, Claudio Santangelo, Francesco Frullini, Angelandreina Rorro, Ludovica Ruggiero, Roberto Ciabattoni

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Innovative applications of 3D printed elastomers in the restoration of Cultural Heritage

Alberta Paglione, *ICR Central Institute for Restoration*, Rome, Italy
alberta.paglione@gmail.com

Carla Giovannone, *ICR Central Institute for Restoration*, Rome, Italy

Angelo Raffaele Rubino, *ICR Central Institute for Restoration*, Rome, Italy

Claudio Santangelo, *ICR Central Institute for Restoration*, Rome, Italy

Francesco Frullini, *ICR Central Institute for Restoration*, Rome, Italy

Angelandreina Rorro, *ICR Central Institute for Restoration*, Rome, Italy

Ludovica Ruggiero, *ALES S.p.A.* at I*CR Central Institute for Restoration*, Rome, Italy

Roberto Ciabattoni, *ICR Central Institute for Restoration*, Rome, Italy

Abstract. This study evaluates the application of innovative materials in 3D printing for the protection and conservation of cultural heritage, focusing on the intervention conducted on the environmental installation 'Spiette, 36' by artist Paolo Icaro at MAXXI, Rome. The main challenge of this artwork's conservation is related to its interaction with the museum's audience. Specifically, the presence of floor-placed elements necessitated a comprehensive approach to ensure their preservation. For this reason, with the artist and museum's support, a project was developed to create exhibition copies and digitally preserve the installation.
The project involved acquiring the shape through 3D scanning and generating its negative by processing the digital model. Extensive research was then conducted to select elastomers introduced to the market in recent years capable of emulating the performance of silicone rubbers for 3D printing molds. The study of these materials and printing techniques has provided valuable insights, laying the groundwork for potential applications of 3D printing elastomers in restoration.

Keywords: 3D printing, elastomers, production of molds, installation art, exhibition copy.

1 Challenges associated with environmental installations.

1.1 The artwork "Spiette, 36"

"Spiette, 36" is an environmental installation created by Paolo Icaro, a Turin-born artist who is still active internationally, recently acquired by MAXXI- National Museum of 21st Century Art, Rome. The artwork consists of thirty-six plaster tiles, each containing a fragment of mirror set at a particular angle. The mirror element serves as the mechanism for setting up the artwork and expressing the artist's intention: through a play of reflections, the tiles are progressively positioned in the environment, including walls, floors, and ceilings. As visitors explore the immersive environment of the artwork, they engage with a captivating interplay of reflections, actively shaping their experience.

Collaborating with the living artist: understanding the artwork and its conservation requirements. The study of the artwork was greatly enhanced by the invaluable contribution of the artist Paolo Icaro, who kindly welcomed us into his studio in Tavullia (Pesaro, PU, Italy) and showed us the entire production process of his work. Observing the artist's firsthand process of working with plaster allowed for a deep exploration of his artistic expression while also highlighting the fragilities of the material due to its execution technique.

In addition, through conversations with Paolo Icaro, we were able to explore themes related to the conservation of his work and potential preservation solutions. The fundamental aspects identified for preservation comprehend the ability to set up the installation elements throughout the environment, including the floor, and ensuring visitors can freely access and navigate the entire space without restrictions.

Fig. 1: (from left) "Spiette, 36"; Paolo Icaro in his studio; element no. 7 front and back.

1.2 Conservation issues and restoration intervention

The thirty-six elements of the artwork displayed uneven conservation conditions, closely influenced by their placement within the environment and, thus, the extent of interaction with the public. The tiles exhibited on the floor have inevitably experienced numerous episodes of accidental impacts and trampling by visitors. For this reason, they displayed numerous fractures, losses, and stains from residue material originating from shoe soles.

Throughout the restoration of the five elements, careful consideration was given to the delicate nature of the constituent material, focusing especially on minimizing mechanical stress and exposure to water. The cleaning process was carried out through a series of tests to identify the most effective system for maintaining the action at the gel-surface interface. Among the different systems, PVA-B (5% polyvinyl alcohol, 1% borax, also with the addition of 15% acetone) was selected [1]. For the reattachment of detached fragments, a solvent-soluble adhesive resin, Mowital B60HH (5%, 20% in ethanol), was selected to avoid the use of water [2]. The plastic reintegration, which the artist wanted to be mimetic, was carried out using a vinyl-acrylic-based plaster, the Red Devil One Time, which can be easily identified under UV light observation and is highly reversible through a ketone such as acetone.

2 Addressing conservation challenges of the exposed artwork through digitalization and 3D Printing

2.1 The development of a production system for exhibition copies

In addition to the restoration intervention, the project also includes the creation of a digital model of each of the thirty-six elements, with the aim of preserving the artwork and creating molds for exhibition copies. This practice is common in contemporary art conservation, especially for installations vulnerable to public damage [3]. The traditional technique of copying using casting materials is unsuitable due to the fragility of the artwork, as it requires direct contact with the original surface. To avoid this potentially damaging phase, the artist Paolo Icaro was offered the opportunity to utilize 3D technology, enabling precise surface detection and providing a versatile digital model with numerous practical applications. Using the digital model as a starting point, the restoration methodology usually requires the creation of an "intermediate" model to obtain the silicone mold. However, due to time and cost constraints, this method proves impractical for our project. An alternative would be to directly print the copy in plastic [4], but this does not meet our specific requirement for a copy made by gypsum and mirror. Therefore, the focus of our study shifted to the possibility of obtaining the negative form directly from the digital model through software processing, thereby enabling the printing of the mold. In this regard, market research was launched on the performance of available materials for 3D printing.

The project is organized into the following phases: acquisition through structured light 3D scanning of the original element; processing of the digital mold; 3D printing of the mold using the selected polymer; insertion of the mirror fragment and pouring of the plaster; demolding and finishing of the positive.

2.2 The aim: obtaining a flexible mold printed in 3D

To overcome the difficulties associated with using a rigid mold, we have selected several classes of 3D printing polymers with elastic behavior similar to silicone rubbers. These elastomers, with their elastic properties, are widely used for a variety of purposes in different fields, including medicine, engineering and fashion [5].

Printing elastomers, in fact, can provide a crucial contribution to the production of copies without coming into contact with the original material, allowing for the easy release of the positive, similar to traditional silicone molding.

Research for suitable materials The experiment compared three different elastomers using two different printing techniques: Fused deposition modeling (FDM) and Stereolithography (SLA).

Elastomeric resins for SLA printing. Numerous formulations of resins for SLA that mimic rubbers have recently been introduced to the market, offering varying degrees of elasticity. Among these, we have selected the American line Formlabs, which offers two elastomeric resins: Elastic 50A and Flexible 80A. The choice is motivated by the extensive documentation provided by Formlabs, including specific guides on printing and usage [6]. The first resin tested was the flexible 80A, methacrylate-based resin, which represents the stiffest elastomer in line with its shore hardness of 80A; it has been on the market since 2014, but its formulation was modified in 2020. The Elastic 50A resin, an Acrylate-based material introduced in 2019, boasts high elongation properties and constitutes the softest material in the line. Thanks to the SLA printing technology, both resins boast extremely high detail resolution, making them suitable for use in fields such as modeling, engineering, and healthcare.

Thermoplastic elastomers for FDM printing. The market has introduced the family of thermoplastic elastomers (TPEs). Within this class, the most common material is thermoplastic polyurethane (TPU), available commercially with a Shore A hardness ranging from 45 to 95. Its characteristics have made it one of the most studied 3D printing elastomers [7]: it is biocompatible, non-toxic, waterproof, and has high shape memory. Above all, it is known for its remarkable resistance to impacts, abrasions, and cuts, qualities that have made it one of the preferred materials to produce medical devices and smartphone covers. Among the TPU polymers on the market, we have selected Raise3D TPU95A.

3D Printing tests It is worth noting that printing technology plays a fundamental role in determining the final outcome of the object. Both technologies build the object layer by layer, but they leverage very different processes: while SLA constructs the object using a laser UV light that selectively hits a liquid resin, triggering its polymerization in layers, FDM works by melting and progressively depositing layers of a thermoplastic polymer [8]. For the experimental work, in order to compare work times and costs, we also printed test samples of rigid polymers (PLA and Tr250 acrylic-based resin from Phrozen). The TPU 95A and PLA were printed using the FDM printer Raise3D N2 Plus, while the Phrozen Tr250 resin and Formlabs' resins were used with the SLA printer Form 3B+. From each printed sample, gypsum positive models were obtained, and their results and potential were analyzed (Fig. 3).

Accelerated aging tests While printing materials such as PLA have been extensively studied and proven suitable for restoration purposes, the three elastic materials - Formlabs resins and TPU - are relatively new and lack the same specialized literature regarding their long-term behavior. For the purposes of the experimentation, it is indeed relevant to measure the plastic deformation of these elastomers under ambient conditions to observe their ability to maintain their original shape and to assess their suitability for repeated use over time. Cycles alternating between ten hours at low temperature (10°C) and high relative humidity (95% RH), followed by ten hours at high temperature (50°C) and low relative humidity (30% RH) were set up, for a total cycle duration of 24 hours (including 4h of transition) repeated twenty-seven times.

The measurement of deformation was obtained by overlapping the digital models obtained from the structured light 3D scanning of the samples using the GOM Atos Compact Scan 5M scanner, carried out before and after the aging cycles. This process was executed using Gom Inspect 2022 software for a direct comparison of the two three-dimensional geometries, providing quantitative measurements of deformations visible in false-color images (Fig. 4).

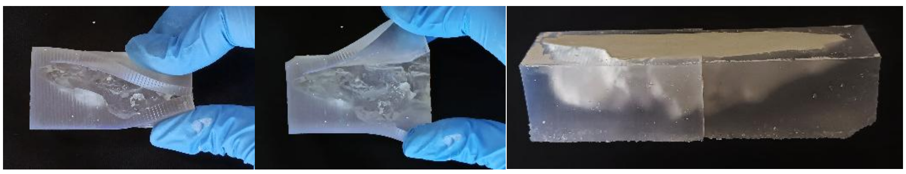


Fig. 2: (left) elastic deformation (right) transparency of Elastic 50A resin.

Fig. 3: Production process of the plaster sample starting from the elastic mold. In the first two cases, the sample broke due to hardness of TPU 95A and Flexible 80A.

3 Experimental Findings and Conclusions

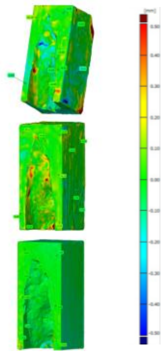
3.1 Considerations on the observed features of tested elastomers

The results of the examination conducted on the five materials were synthesized in a table (Tab.1), which includes the main aspects observed during the study: digital model processing time, printability, post-printing processing times, production costs, replicating surface details and morphological features, ease of use and ability to maintain their geometry over time.

The rigid polymers PLA and Tr250 are not the most effective options in terms of overall working time. In contrast, TPU offers advantages such as affordability in both material and printing methods, along with biocompatibility, non-toxicity, and adaptability to varying hardness levels. However, TPU printing requires significantly longer times and extensive testing. Furthermore, final processing is complex due to the need to address blemishes caused by printing stringing phenomena. On the other hand, the two Formlabs resins do not present the same disadvantages. The printed object does not need to undergo finishing processes as the printing SLA technique ensures high accuracy and precision in surface finish. In summary, in terms of production times, the two Formlabs resins represent the most efficient materials. Their disadvantage, instead, lies in the high costs.

Regarding the results of the aging cycle to which the three elastomers were subjected, measurements of plastic deformation showed the high ability of the three polymers to retain their shape (Fig. 4). The Elastic 50A showed a maximum deformation of +0.10 and -0.17 mm; the Flexible 80A resin of +0.15 and -0.08 mm. The TPU 95A specimen, on the other hand, with its maximum deformation of +0.06 and -0.06 mm, demonstrated a particular ability to withstand thermo-hygrometric stresses, partly due to its greater rigidity compared to the other two materials with lower Shore values.

Tab. evaluation of the five printing materials	PLA	Tr250	TPU 95A	Flexible 80A	Elastic 50A
Reduced digital model processing times	•	•	•••••	•••••	•••••
Easy of printing	•••••	••••	•	••••	••••
reduced post-printing processing times	•	•••••	•	•••••	•••••
Reduced production costs	•••••	••	•••••	•	•
Surface and morphological feature yield	•	•••••	••	•••••	•••••
Ease of use (positive demolding)	•	•	•••	•••	•••••
Ability to maintain its geometry over time.	-	-	•••••	••••	••••



Tab. 1: Final evaluations on the tested materials assigning a score to each one.
Figure 4: Overlay of digital models for measuring maximum deformation. In order: Elastic 50A, Flexible 80A, TPU 95A.

3.2 Evaluating the best material choice for Spiette, 36 and the production of exhibition copies.

Based on test results, we selected the Elastic 50A for printing the molds for the intervention on "Spiette, 36". It is indeed the material with the most pronounced elastic properties (50A shore) and the high detail resolution (SLA printing technique).

Practical Application of Elastic 50A Elastomer. Three elements of the installation were selected to represent the various cases based on shape (a corner piece) and surface characteristics (smooth or irregular elements).
Scanning 3D. The three elements were scanned in 3D using the GOM Atos Compact Scan 5M blue structured-light scanner, covering the mirror fragments.

Digital processing. The obtained digital model was imported and processed using the software Geomagic Wrap and Cinema 4D for mesh cleaning and digital mold generation from the object's surface. It was decided to maintain a mold thickness of 1 cm, similar to the silicone layer in traditional craftsmanship, in order to reduce production costs.

Printing 3D of the elastic mold. The printing process, as we have seen, was carried out using the desktop SLA printer Form 3B+ using a UV laser (405 nm). At the end of the process, the object undergoes washing with isopropyl alcohol, and the post-curing phase begins, which allows for the completion of resin residue cross-linking. Finally, the printing support structures are manually removed. In order to maintain the geometry of the elastic material unchanged during subsequent phases, a rigid external counterform was designed and printed in PLA.

Creation of the plaster copy. First, the mirror fragment was securely placed in its housing, and then the liquid plaster was poured into the mold. After the plaster had been set, the flexible cast containing the plaster positive was extracted from the rigid containment mold and delicately handled to allow the gradual removal of the copy.

On the surface of the replica, upon close observation, the thin lines of the layers are visible. We decided to preserve them as a recognizable feature of the replica compared to the original (Fig. 6).

Fig. 5: Elastic deformation of the printed Elastic 50A counterform of element no. 29.

Fig. 6: (from left) Demolding of the positive from the printed Elastic 50A mold; original element No. 29 and exhibition copy comparison; detail of the area characterized by printing layer lines on the copy.

Potential applications of printable elastomers in the Cultural Heritage field. This initial approach to the printable elastomers has showcased the potential of new 3D materials. In the case study presented Formlabs Elastic 50A resin emerges as particularly promising, offering a favorable combination of elasticity, detail accuracy, and surface quality, making it well-suited for our application of producing exhibition copies with minimal processing time.

However, the range of elastomers for 3D printing encompasses various materials with diverse performance characteristics and Shore hardness formulated for most printing techniques. Generally, these product classes boast advantages such as elastic deformation capability, exceptional resistance to impacts, abrasions and cuts, and in some instances, complete non-toxicity and biocompatibility (TPU). Above all, their printability allows for shaping as desired without direct contact with the artwork. These features suggest potential applications beyond mold production examined in this study. For example, due to their remarkably high resistance to external impacts compared to rigid materials, they can significantly contribute to the study of artwork protection during handling, transportation, and storage processes.

Ultimately, this research aims to open up possibilities for further research into material characterization and long-term durability to amplify our knowledge about the new polymers of 3D printing and how to use them for the conservation of cultural heritage.

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