APPLICATION IN CULTURAL HERITAGE OF STEREOLITOGRAPHY TECHNIQUES FOR THE 3D REPRODUCTION

M. Frigione*, F. Montagna

Department of Innovation Engineering, University of Salento, Italy – (mariaenrica.frigione, francesco.montagna)@unisalento.it

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ABSTRACT:

With the use of stereolithography, one of the most widespread and old rapid prototyping techniques, it is possible to reproduce objects, damaged or missing parts, faithful replicas of interest in the field of Cultural Heritage. In this work, some of the applications of the stereolithography technique to replicate objects or missing parts of artistic or cultural interest, are illustrated. The aim of the Authors is to highlight the potential, the advantages, and also the limits if any, of this technique when applied in the field of Cultural Heritage for various needs, reporting some real cases of objects obtained in the laboratory with stereolithography.

1. INTRODUCTION

Stereolithography is one of the most widespread rapid prototyping techniques and among the first appeared on the market. It allows for the rapid creation of prototypes with even extremely complex geometry. This technology has already been used for long time in the manufacturing of polymeric and ceramic materials. Due to its versatility and the precision of the objects obtained, it has been also adopted in a rather distant field, such as that of Cultural Heritage (Arnold and McAllister, 2007).

With this technique, it is possible to produce/reproduce objects of any shape, and almost any dimension (depending on the available machine), starting from their digital representation obtained by drawing any object using a 3D modelling software or from the scan of a geometry of a real article (Bernardini et al., 2002; Pavlidis et al., 2007). The digital representation is elaborated using a specific software to identify the proper strategy for the 3D building. The resulting file is, then, sent to the stereolithographic machine for the production stage. The 3D prototype is, finally, built starting from an initially liquid synthetic resin which is hardened into the desired shape by means of light (for instance: UV) radiations.

In Cultural Heritage sector, the stereolithography techniques can allow the reconstruction of ancient and valuable objects and/or the replication of vulnerable finds, and these processes can be carried out with an extreme precision. With this technology, furthermore, it is possible to obtain a faithful reproduction of an object which can be displayed to the public instead of the original which may be damaged, vulnerable or very valuable. The need to replicate an object, in fact, can also arise from its rarity or even uniqueness. Faithful replicas may still be needed to study the characteristics and finishes of antique items, without damaging the original ones. Furthermore, with the same technique damaged or missing parts of an ancient object can be reconstructed, once the features of the original parts are known.

Concerning the costs of stereolithographic techniques, with recent innovation in processes, they are now competitive with those of traditional craftsmanship, with the advantage of obtaining objects with more valuable finishing characteristics. This represent an important point when a faithful reproduction of an object, with an excellent surface finish, is required. In addition, stereolithography allows to reach a degree of accuracy and detail in the replicated objects not obtainable with more traditional methods (Balletti et al., 2017; Balletti and Ballarin, 2019).

Furthermore, although rapid prototyping methods based on stereolithography are more expensive than traditional techniques (the initial cost of the machine is quite high), these techniques are quite insensitive to the geometric complexity of the piece to be built. The same cannot be said for traditional craftsmanship, in which the geometric complexity parameter strongly affects the production costs of the final object as well as the processing times. In these cases, therefore, stereolithography becomes an incomparably useful tool also in the field of Cultural Heritage.

The purpose of this work is to illustrate the most commonly used resins and the available machines and to give an overview of the possible applications of the stereolithography technique, using a machine employed for research purposes, to replicate in the laboratory objects or missing parts of artistic or cultural value, pointing out the feasibility of the process and the precision of the technique.

2. MATERIALS AND METHODS

2.1 The resins

The material typically employed in a stereolithography production is a liquid resin, based on acrylic or epoxy monomers or a mixture of these two synthetic resins. The liquid resins are diluted in solvents and oxides are added which, activated by light, release reactive groups which trigger the polymerization process, which for this reason is referred to as “photo-polymerization”. This chemical process allows the resin to pass from a liquid to a solid state, maintaining the shape and geometry imposed by the machine.

As this technique has progressed, different classes of resins have been developed with different performances according to the specific needs.

* Corresponding author

Low-cost (standard) resins are available which, however, offer only limited performance in terms of thermal and mechanical resistance. Due to their limited glass transition temperature (not exceeding 50°C), in fact, they can only be used to make prototypes and/or objects for indoor applications: they are not suitable to produce finished objects or components, even in the field of Cultural Heritage.

On the other hand, resins with special performance are available. For example, resins resistant to high temperatures can be employed, i.e. characterized by a glass transition temperature around 100°C. For different purposes, resins with characteristics of flexibility and even elasticity can be selected: at the beginning of the development of stereolithography techniques, in fact, photo-polymerized resins displayed a markedly brittle behavior (Chantarapanich et al., 2013).

An important feature in the field of Cultural Heritage is that the resins used in stereolithography must have a good compatibility with varnishes, stuccos and paints: components made using this technique can, then, be painted to match the appearance of the parts they replace (as we will see later). The resins for stereolithography currently available on the market also have these features.

2.2 The stereolithography machines

It is possible to state that the stereolithography technique represents the progenitor of additive manufacturing techniques.

The first stereolithography machines were commercialized at the beginning of the nineties. The reference market was almost exclusively the industrial one, a sector that could benefit from a drastic reduction in prototyping times, especially for the creation of products with complex geometries. Even the handicraft sector, albeit with longer times due to the high economic investment and personnel training, was able to benefit from the new prototype manufacturing technology, for example, in the field of jewelry. Subsequently, the potential of these techniques promoted the development of new machines equipped with software, available at lower costs and with performances adaptable to specific applications, thus expanding their field of use.

In the field of Cultural Heritage, the adoption of this technique has allowed the faithful reproduction of ancient objects, the manufacture of missing, damaged or deteriorated parts, the creation of settings or models, just to give some examples. In this sector, stereolithography is among the best additive manufacturing techniques also because it is able to guarantee the best finish of the objects produced (Gebhardt, 2017). This aspect is due to the possibility of creating very thin layers of resin, deposited one on top of the other (i.e., the digital model is “sliced”), until the final object is formed: this is, in fact, the only technique currently available that allows for layering with thicknesses of the order of twenty thousandths of a millimeter (Scopigno et al., 2015). In this way it is possible to obtain a very detailed finish, the layering is practically invisible to the naked eye.

The energy source that allows the resin to polymerize, therefore passing from the liquid to the solid state, is an ultraviolet laser radiation. The development of laser technologies in recent decades has contributed to greatly improve the finish of the parts produced with these techniques. On the other hand, with the transition from the expensive and short-lasting gas laser to the much more efficient, economical and long-lasting solid-state laser, it has been possible to develop cheaper machines able to satisfy any sector, including the Cultural Heritage one. Technological progress in this field made it possible to select the proper machine for any application, for example based on the size of the piece to be made, with a very high finish and a low risk of machining failure.

3. CASE STUDIES

3.1 Reconstruction of damaged or missing parts

In a first experience, the missing upper part (neck and part of the handles) of a nineteenth-century amphora was reconstructed. The reconstruction of the missing part started with solid modeling with 3D graphics software. Figure 1 illustrates the phases of the graphic modeling of the component to be reconstructed.
Once the modeling phase was completed, the file of the 3D model was converted into a format that allowed it to be compatible with the software of the stereolithographic machine. The latter machine (i.e. a SLA 250 Stereolithography, supplied by 3D System Company, shown in Figure 2) was able to generate a prototype starting from a photo-polymerizable liquid epoxy resin that hardened upon exposure, layer by layer, to a radiation of a proper wavelength. Therefore, the prototype was built by reproducing in the resin, layer by layer, the design obtained through the 3D model.

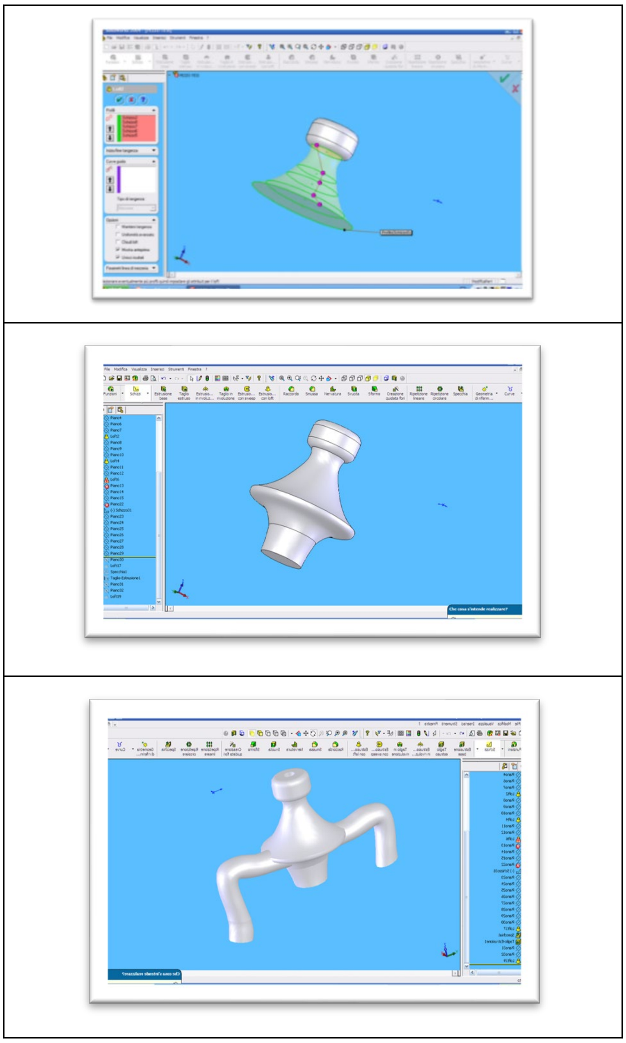

Figure 1. Different phases of the graphic modeling of the missed component to be reconstructed.

Figure 2. SLA 250 Stereolithography machine.

The curing process of the prototype was, finally, completed in an oven by its exposure to UV radiations. The obtained prototype is shown in Figure 3, together with the original amphora with the missing part handcrafted.

From the observation of the picture in Figure 3, it is noted that the prototype built in resin with the stereolithography technique was more precise, with an excellent rendering of the details. Dimensional stability was equally excellent, with no material shrinkage, i.e. the prototype dimensions were exactly the same as the design ones. The object obtained was transparent, yellow in color and with an internal "honeycomb" structure. In fact, in this way it was possible to speed up the production process and limit the consumption of material. The mechanical properties of the obtained object were not high; on the other hand, the new component was not expected to undergo such high stresses as to require a more resistant structure. However, the color and aesthetic appearance of the prototype (yellowish and full of bubbles) was not suitable to be directly used as integration into the amphora. Therefore, it could be possible to apply a white varnish on its surface to make it suitable for restoration operations. Alternatively, it is also possible to use a liquid resin with the addition of an opaque filler directly in the stereolithography process.

In conclusion, with the direct construction of the missing piece in resin, it is possible to exactly replicate the required object and create it in a relatively short time, the latter depending also on the complexity and size of the piece. The resin prototype made in this experience was of poor quality from an aesthetic point of view: it could have been suitably coated to make it more similar to the original amphora in which it was integrated. Finally, the prototype in resin can be also used to construct two half-molds in which to pour a ceramic suspension with which to make the missing part in ceramic material (Fersini et al., 2009).

Figure 3. Prototype in resin obtained with the stereolithography technique (forward), with the original amphora (in the background).

3.2 Faithful reproduction of delicate or precious objects

The possibility of reconstructing in resin an archaeological relic, or an object that cannot be exhibited to the public because it is too vulnerable or precious, strictly depends on the acquisition of the detailed geometry of the object in order to convert it into a CAD file (Bandiera, 2007; Bandiera et al., 2013). Once obtained the CAD file, it is possible to use this file in an stereolithography to build a faithful replica of the object to be displayed in a museum.

Following this procedure, faithful replicas of some wooden objects that were not possible to expose in museum exhibitions because they were very delicate (i.e. deteriorated archaeological wooden relics), have been created. The replicas were produced starting from a liquid epoxy resin, hardened layer by layer through a "photo-polymerization" chemical reaction induced by a laser beam, on the basis of the 3D representation of the objects. The laser selectively scanned the surface of the liquid resin bath determining its polymerization up to a depth of 0.1 mm, in the present case (resolution in the vertical direction). Thus, the precision in the plane obtained with the stereolithography was of the order of 0.1 mm. The machine used in the process was a SLA 250 Stereolithography (3D System, shown in Figure 2).

In Figure 4, the replicas of some wooden artefacts, obtained by stereolithography according to the procedure previously described, are displayed.

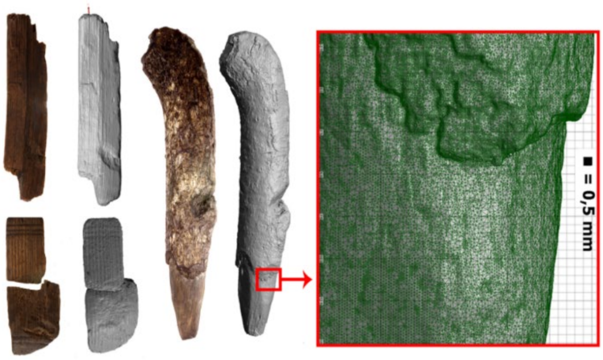

Figure 4. Replicas of wooden artefacts exhibited at the Supersano museum (Montagna et al., 2007).

Also in this case, the precision of the technique is confirmed, as observable in Figure 4, which allows the wooden relics to be replicated exactly, so that no superficial detail was lost.

In another project, with the same technique, and following the same procedure previously illustrated, replicas of some farmworker tools (i.e. sickle, axe) from the Middle Ages, were created.

Figure 5. Replicas of a sickle and an axe from the Middle Ages. In the picture above, the replicas just made in resin with stereolithography; in the picture below, the same replicas after being painted to look similar to the original objects (in iron).

The tools were found in a water well which had allowed them to be kept in good condition thanks to the favorable pressure levels and lack of oxygen. On the other hand, due to their age, vulnerability and fragility, it was not possible to exhibit the original artifacts.

In order to show their faithful replicas to the public, the original tools were first scanned by laser scanner, obtaining their very faithful digital reproduction. Therefore, the replicas in resin were obtained by means of stereolithography (shown in Figure 5, image on the top). A post-production process, carried out by a restorer, consisted of painting and finishing the replicas in resin. After this additional step, two replicas were obtained which were difficult to distinguish from the originals (visible in Figure 5, image on the bottom), which were displayed to the public, without the need to endanger the original tools.
Small silver Athenian coin, very ancient (510-490 b.C.) and precious, was replicated with the stereolithography technique. The silver coin is part of a private numismatic collection, it bears an owl on one side and an Attic amphora on the other (Siciliano, 2016), as shown in Figure 6.

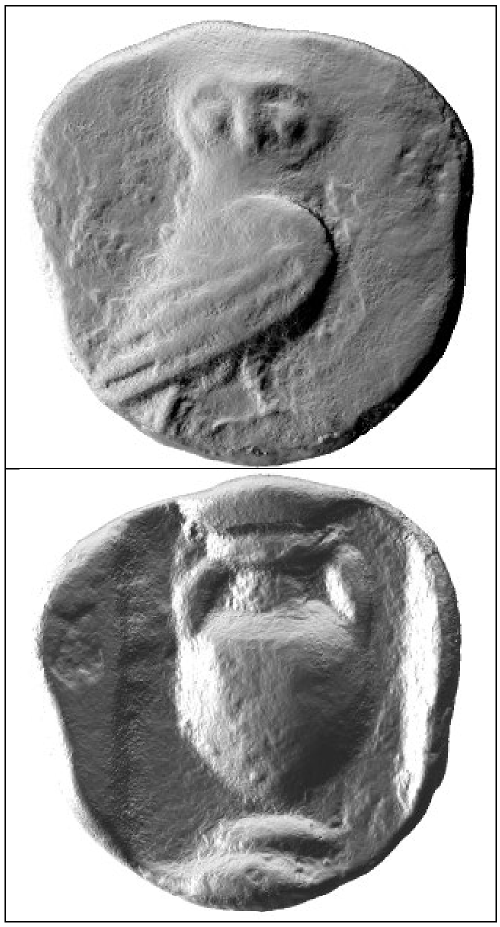

Figure 6. The small silver Athenian coin (510-490 b.C.).

Also in this case, the 3D drawing of the object was first created starting from a scan of the coin. The drawing was, then, transformed into a file which was transferred to the stereolithography machine (SLA 250 Stereolithography, 3D System, Figure 2). Using this procedure, it was possible to faithfully replicate the small coin in resin, as shown in Figure 7.

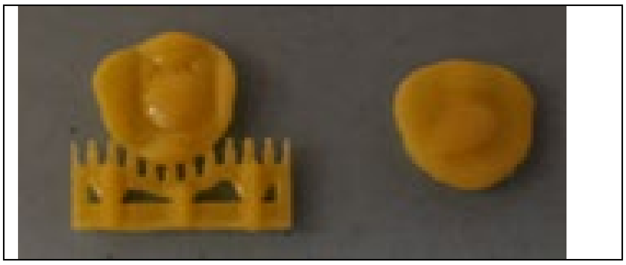

Figure 7. Replica of the small silver Athenian coin in resin (yellow color); both sides are shown.

The coin in resin was built layer by layer, starting from the drawing; the resin was hardened upon exposure to UV radiations in the stereolithography machine (Frigione et al., 2016). A silver paint was, finally, applied on both sides of the coin in resin: the replica, shown in Figure 8, represented the exact reproduction of the original small silver coin.

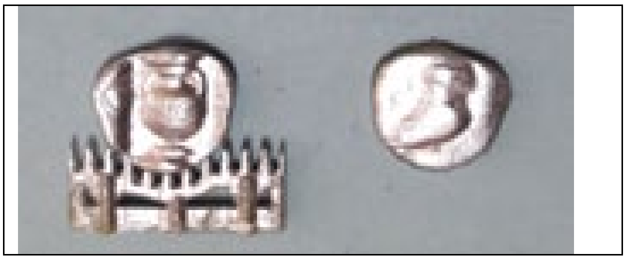

Figure 8. Replica of the small silver Athenian coin painted in silver color.

This further example confirmed that the combined use of 3D modeling and the stereolithography technique allows the reconstruction of ancient, precious or vulnerable objects to be carried out with extreme precision and to allow their exhibition to the public.

3. CONCLUSIONS

In the field of Cultural Heritage, the stereolithography technique allows the faithful reproduction of ancient objects, the manufacture of missing, damaged or deteriorated parts. In the present work, some of the applications of the stereolithography technique carried out in the Laboratory by the Authors and aimed at replicating highly delicate and fragile objects or at reproducing of missing parts of artistic or cultural interest, have been illustrated. In the various illustrated examples, the possibility of adapting the process to any specific need and the precision of the technique are highlighted.

REFERENCES

Arnold III, J.B., McAllister, M.L.M., 2007: Artefact replication by stereolithography. International Journal of Nautical Archaeology 27(2), 160-165, Article No. na 980166.

Balletti, C., Ballarin, M., Guerra, F., 2017: 3D printing: State of the art, considerations and future perspectives. Journal of Cultural Heritage 26, 172–182. Doi: 10.1016/j.culher.2017.02.010

Balletti, C., Ballarin, M., 2019: An Application of Integrated 3D Technologies for Replicas in Cultural Heritage. ISPRS International Journal of Geo-Information 8(6), Article No. 285, 1-29. Doi: 10.3390/ijgi8060285.

Bandiera, A., 2007: I modelli 3D digitali dei reperti lignei. *Quaderni del Musa 1: La Storia nel Pozzo, Ambiente ed Economia di un Villaggio Bizantino in Terra d’Otranto*. P. Arthur, G. Fiorentino, A.M. Grasso, M.L. Imperiale Eds., UniSalento Press, 49-50. ISBN: 9788896515082.

Bandiera, A., Arthur, P., Imperiale, M.L., Frigione, M., Montagna, F., Maffezzoli, A., Signore, G.M., 2013: Replicating degradable artefacts. A project for analysis and exhibition of early medieval objects from the Byzantine village at Scorpo (Supersano, Italy). *Proceedings of the 1st International Congress on Digital Heritage, Digital Heritage 2013*. Marseille; France; October-November 2013; Federating the 19th Int'l VSMM, 10th Eurographics GCH, and 2nd UNESCO Memory of the World Conferences, Plus Special Sessions fromCAA, Arqueologica 2.0 et al. Vol. 1.

Bernardini, F., Rushmeier, H., Martin, I.M., Mittleman, J., Taubin, G., 2002: Building a digital model of Michelangelo's Florentine Pieta. IEEE Computer Graphics and Applications 22(1), 59 – 67. DOI: 10.1109/38.974519.

Chantarapanich, N., Puttawibul, P., Sitthiseripratip, K., Sucharitpwatskul, S., Chantaweroad, S., 2013: Study of the mechanical properties of photo-cured epoxy resin fabricated by stereolithography process. Songklanakarin Journal of Science and Technology 35(1), 91-98.

Fersini, M., Frigione, M., Matteo, S., 2009: Dall’High-Tech alla Ceramica Tradizionale – Un esempio tutto Salentino di ricostruzione di lacune ceramiche con l’ausilio della tecnica stereolitografica laser. *Quaderno 12 – Museo della Ceramica di Cutrofiano*, Congedo Ed., Galatina, Lecce, Italy, ISBN: 9788880868897.

Frigione, M., Montagna, F., Bandiera, A., 2016: Riproduzione della moneta in resina. *Pubblico e privato: sinergie interdisciplinari volte alla conoscenza, valorizzazione e tutela dei Beni numismatici. Un caso concreto*. Notiziario del Portale Numismatico dello Stato, N. 9. Ministero dei Beni e delle Attività Culturali e del Turismo, Direzione Generale, Archeologia, Belle Arti e Paesaggio, 12-14. ISBN 978-88-909978-3-9.

Gebhardt, A., 2017: AM-Based Evaluation, Reconstruction, and Improvement of Cultural Heritage Artifacts. *Mixed Reality and Gamification for Cultural Heritage*. Ioannides, M., Magnenat-Thalmann, N., Papagiannakis, G. Eds. Springer International Publishing, 527-549. Doi: 10.1007/978-3-319-49607-8_21

Montagna, F., Frigione, M., Maffezzoli, A., 2007: Replica di reperti lignei per prototipazione rapida. *Quaderni del Musa 1: La Storia nel Pozzo, Ambiente ed Economia di un Villaggio Bizantino in Terra d’Otranto*. P. Arthur, G. Fiorentino, A.M. Grasso, M.L. Imperiale Eds., UniSalento Press, 51-52. ISBN: 9788896515082.

Pavlidis, G., Koutsoudis, A., Arnaoutoglou, F., Tsioukas, V., Chamzas, C., 2007: Methods for 3D digitization of Cultural Heritage. Journal of Cultural Heritage 8(1), 93–98. Doi: 10.1016/j.culher.2006.10.007.

Scopigno, R., Cignoni, P., Pietroni, N., Callieri, M., Dellepiane M., 2015: Digital Fabrication Techniques for Cultural Heritage: A Survey. Computer Graphics Forum 36(1), 1-17. Doi: 10.1111/cgf.12781.

Siciliano, A., 2016: Introduzione. *Pubblico e privato: sinergie interdisciplinari volte alla conoscenza, valorizzazione e tutela dei Beni numismatici. Un caso concreto*. Notiziario del Portale Numismatico dello Stato, N. 9. Ministero dei Beni e delle Attività Culturali e del Turismo, Direzione Generale, Archeologia, Belle Arti e Paesaggio, 1-3. ISBN 978-88-909978-3-9.

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