"Bronzi Di Riace" Geomatics Techniques in Augmented Reality for Cultural Heritage Dissemination

Vincenzo Barrile, Antonino Fotia, Ernesto Bernardo

Abstract: In the 'Museo Archeologico Nazionale della Magna Grecia' in Reggio Calabria (south Italy) are located two full-size bronzes cast around the 5th century BC: The Riace Bronzes; thanks to their outstanding manufacture, they truly represent significant sculptural masterpieces of Greek art in the world. This paper describes the methodology used by the Geomatics Laboratory of the DICEAM of the Mediterranean University of Reggio Calabria to achieve a 3D model of the two sculptures. The 3D modelling is based on the use of imaging techniques, such as digital photogrammetry and computer vision. The achieved results demonstrate the effectiveness of the technique used in the cultural heritage field for the creation of a digital production and replication through 3d printing. Moreover considering that in the renewed interest in the context of international museological studies, Augmented Reality innovation represents a new method for amplifying visitor numbers into museums despite concerns over returns on investment, the procedure to develop a touristic app is described. In fact the enhancement of cultural heritage through the use of 3D acquisition and modeling tools represents one of the fields of study that will see rapid development in the near future. Thus, in order to further valorize and disseminate archaeological heritage, we are developing an app for tourism purposes. The created app allows the user, in real time, to obtain additional information on the object of investigation, even allowing them to view the 3D model in AR. Moreover, the app combines AR and VR technologies with the opportunities offered by 3D printing,

Keywords : 3D Model; 3D Printing; Virtual reality; Augmented Reality.

I. INTRODUCTION

The National Archaeological Museum of Reggio Calabria has been recognized among the most prestigious archaeological museums in Italy1 , so in view of a revaluation of the artistic and cultural heritage, which especially in recent years is no longer seen as an argument of interest only for specialists but also and above all as a tool for the socio-economic development of the territory,

we have taken into consideration the possibility of favoring the entry into the Reggio Calabria Museum of new technological tools, such as Augmented Reality (AR) and Virtual Reality (VR). We want to encourage a modern approach to the use of cultural heritage through the use of these new technologies, already successfully applied by other institutions and foundations such as the Musée d'Art et d'Histoire in Geneva or in Italy in Rome at the Terme di Diocleziano. The application of these technologies allows us to offer users an incredibly more immersive experience than the classic visit to a museum can offer, but not only. Thanks to VR it will be possible for users to visit the museum even before setting foot or to view works that for logistic reasons cannot be physically exposed, furthermore using the AR it is possible for the museum to create references to the works on the territory present in the museum to increase engagement. To this end, 3D scanners and computer graphics have proved to be very powerful tools for creating static or interactive models, through the creation of three-dimensional models that allow access to the general public to artworks that cannot be exhibited due to lack of space or that could otherwise be degraded or damaged. The most valuable works in the National Archaeological Museum of Reggio Calabria are the "Bronzi di Riace", recovered in 1972 representing one of the most significant examples of classical Greek art1. In fact every physical contact, with casts or other, with works like the "Bronzi di Riace" necessarily leads to a degradation of the artwork. And it is for this reason that the creation of highly detailed three-dimensional models, whose relief occurs without requiring direct physical contact with the works, and the subsequent 3D printing of the created model, make it possible to guarantee the fruition of the work without affecting its duration in the time. With the use of technology at the base of 3D printing it is possible to produce copies faithful to the original which allows us to use them for exposures subject to atmospheric agents or other aggressive agents, allowing the use of works in places other than those in which they are exposed to and from which they cannot be moved without significant costs and risks during and for their transport. Furthermore, the three-dimensional models created can be implemented in apps that can be accessed from smartphones that allow museum visitors, through AR, to have access to an incredibly greater amount of information than they are commonly exposed to during the use of an artwork, just think of the possibilities connected with the use of video or audio during the use of the work,

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or the possibility of creating different thematic routes depending on the choices made by the user on the app during the visit, thus offering a much more user-oriented experience that is no longer forced to follow paths predetermined by the museum curator. Likewise, by making use of VR, the user can access historical reconstructions of events or places linked to the works on display so as to be prepared to view them in an active and non-passive way as we are commonly accustomed to considering a visit to the museum. For such reasons the Laboratorio Geomatico of Reggio Calabria has decided to engage in the development of an app for tourist and academic purposes that allows to take advantage of the threedimensional reconstruction of the finds present in the National Archaeological Museum of Reggio Calabria through the AR when one is inside and VR if you want to view some works without physically accessing the structure. Furthermore, an app is being designed that offers the user the possibility of requesting the three-dimensional printing of some works or some of their reconstructions.
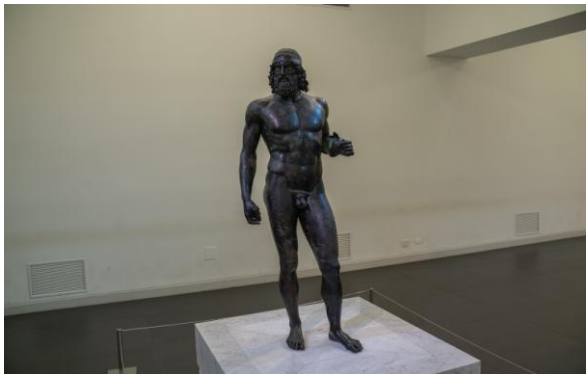
a)

b)

Fig. 1.   Bronzes Statue located at Museo Archeologico of Reggio Calabria (Italy): a) Bronze A; b) Bronze B

II.   MATERIAL AND METHODS

A. Survey and 3D Modeling

In the last decade, one of the technologies that has increasingly been affirming, especially for its relatively low cost compared to the quality of the results, is photogrammetry. This technique is based on the principle structure from motion (SfM), which is the most widely used technique of range imaging in computer vision[2]. Through photogrammetry to the theoretical principles of collinearity, intersection of projective rays, camera calibration, the typical algorithms of robotic vision are used, which allow to analyze and correlate digital images quickly and automatically[10]. The logic behind SfM is that by acquiring the image of an object from different perspectives we are able to obtain a three-dimensional reproduction of the same, applying specific algorithms to the photos. Practically with these software the principle of stereoscopic vision is exploited, which is the one used by human eyes to return three-dimensional images, according to which if you have two photographs of an object whose centers are placed at sufficient distance between them, indicatively between 1/10 and 1/5 of the distance existing between camera and object, it is possible to reconstruct a three-dimensional image of the same, so making a series of photos it is possible to create a three-dimensional digital model of the object captured by the lens. The fundamental characteristic that the 3D digital model must possess is to be metrically correct: this means that the model must be in the right scale and it must be possible to make precise measurements on it. A second important feature, although not fundamental, is that the color must be realistic: this condition is not always necessary and depends on the purpose for which the 3D model is created. In the case of a model that must be used on the web or on applications for tablets and smartphones, it is important that the color is realistic; it is not fundamental in the case of a model created in function of a reproduction in 3D printing being this technology not able to reproduce color[11]. In order to obtain a good result we must be secure that the adjacent digital images overlap each other for at least 80% laterally and at least 30% vertically. The final quality of the three-dimensional model depends directly on the resolution of the photos and therefore on the camera and the optics used for the survey campaign. The redundancy of the data depends on the survey campaign, as we have seen, the images must overlap, and it is this redundancy that guarantees the complete and realistic reconstruction of the model. Finally, since the model we want to achieve must be metrically accurate, we will have to foresee the positioning and an accurate survey of the constraints. For our major campaign, we used a Canon EOS 6D which is a 35 m Digital Single Lens Reflex (DSLR) full-frame. It features a 20.2 megapixel full-frame metal oxide semiconductor (CMOS) image sensor and an ISO range of 100-25,600, expandable to L: 50, H1: 51,200 and H2: 102,400, for higher quality image, even in poor lighting conditions. The effective pixel size is 26.2 megapixels, which are more than enough to achieve a high resolution of the three-dimensional model. In order to guarantee the above, we have provided a grip point every 10 degrees to cover a corner and repeated the operation for different heights as shown in the figure 2:
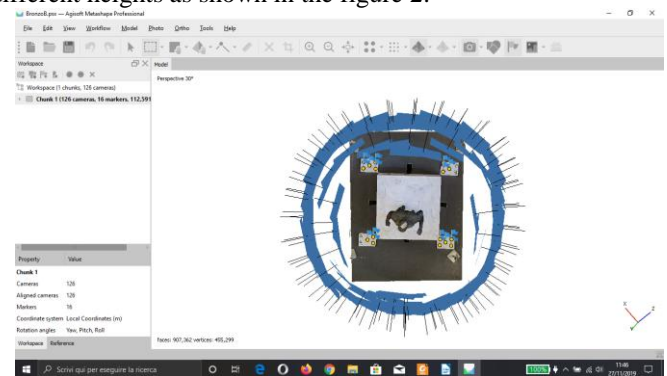

Fig. 2.   Camera positions

It can also be seen how markers were placed at the foot of the works that serve to guarantee the dimensional correspondence between the digital model and the real work, actually acting as constraints, even if the software used succeeds in obtaining dimensional results corrected without requiring physical constraints.

To make the three-dimensional model we used the commercial software Metashape produced by Agisoft. Which through the elaboration of the photographs that the user as input is able to construct the texture of a three-dimensional model.

To do this it operates through three main phases:

1. The first phase is the alignment of the photographs.

2. The next phase is the construction of geometry.

3. The last step is to structure the generated mesh or use ortho-generation3.

In the alignment phase PhotoScan looks for common points between the various images and matches them, at the same time it calculates the position of the camera for each image and perfects the calibration parameters of the same. It then outputs us a scattered point cloud and the positions of the camera3. This is because by deducing the position taken by the individual photographs it is possible to deduce by triangulation the position of the objects present in them and from this position obtain the three-dimensional model of the same. To deduce the position of the photos makes use image matching algorithms that identify key points that are easily recognizable in three or more images, in fact they are those constraints that serve to guarantee a metric correspondence between model and real object.

Starting from the key points, through a photogrammetric triangulation procedure to star projective (better known as bundle adjustment), in an automatic way the camera is calibrated (internal orientation: calculation of the focal length and the principal point) and the shooting position is rebuilt of the single photographs (external orientation: coordinates of the gripping centers and rotations of the frame), and for each key point the real coordinates x, y, z are obtained, which are

three-dimensional materialized in a sparse points cloud, that is in a cloud of points to low density (sparse reconstruction).

In the second phase, based on the positions of the points of the sparse point cloud, it is thickened to generate a dense point cloud, to do this it uses the coordinates of the points obtained in the first phase to estimate the position of the intermediate points in order to thicken the point cloud .

This dense point cloud can be interpreted as a raw data, that is, it is nothing more than a series of coordinates (x, y, z) of the points.

After the creation of the dense point cloud, the software generates a continuous polygonal surface, that is a 3D polygonal mesh, which represents the surface of the object we are detecting through a triangular mesh, and each of these triangles has a vertex in one of the points of the cloud previously generated.

Generated the mesh we can edit the same in order to improve the final result, however this operation is limited. In fact, within Metashape, we are only allowed to eliminate polygons or repair any holes in the mesh, if we need to intervene more markedly we must necessarily resort to third part software.

The mesh originally has no color, so it must be assigned to the polygons. The color can be attributed to the polygons that make up the mesh in two different ways: through color-per-vertex or texture mapping.

The first consists in mediating on each triangle of the mesh the color that each of its three points originally had in the dense point cloud, while the second involves the use of the starting images, or being the same already oriented with respect to the model, their color is projected onto the latter and give rise to a square texture on the model.

The choice between the two depends mainly on the quality of the photos and their number, in fact with the second method the quality of the final result is independent of the density of the dense point cloud but it is influenced by the quality of the photos, in the case of the relief of museum finds

however it is good to always resort to texture mapping as it is a result more in keeping with the original model.

The generated three-dimensional model can then be exported in various formats that can be edited by different software, in our case it was exported in stl format (acronym for Standard Triangulation Language) and then used to create a physical model of the Bronzes printed in 3D.

Moreover as known, the methodologies for the realization of 3D models are manifold and each one presents different accuracy level of details, depending from the instrumentation and the methodology used related to the final use to which the work is destined.
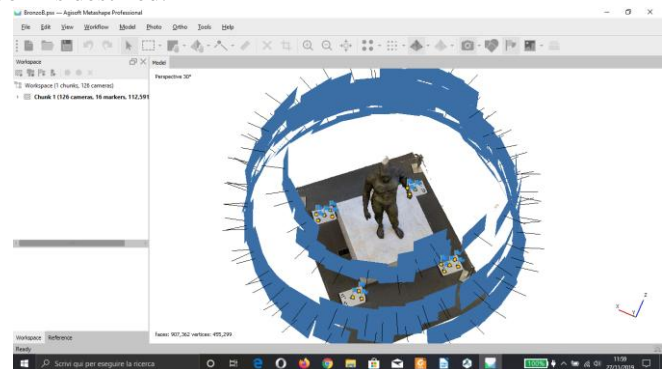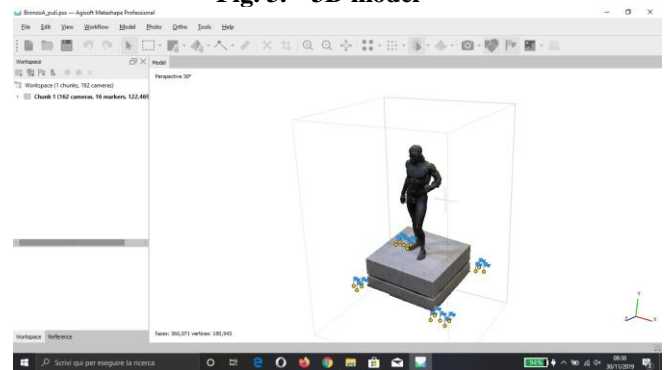

Fig. 3.   3D model

Fig. 4.   3D model

In this case, because the didactic nature and the touristic finality of the application, the metric accuracy of the 3d model assumes a lower importance than the need to visualize its shape.

For this reason, we decided to carry out the 3D survey of the National Archeological Museum, in a "fast way", using directly a dataset obtainable from Google Earth, and then processed by classical photogrammetric techniques.

Clearly, as we aspect, the precision between the model generated by this application present an accuracy lower than 3d model generated with laser scanner or UAV.

Fig. 5.Museo 3D model

B. 3D Printing

Rapid prototyping or 3D printing allows the production of physical models starting from a digital model, all in the scale and with the definition set by the user.

Before the advent of this technology to obtain a physical model perfectly corresponding to the reality of an object, such as a work of artistic interest or an archaeological find, it was necessary to resort to plaster casts of the same, but this operation risked of inevitably to degrade the artwork in addition to the tangible risk of damaging it during surveying or handling operations. Furthermore, the objective impossibility of scaling the work necessarily led to the making of copies on a 1:1 scale, which would be desirable for surveys that served for the mere realization of a copy of the

original but made it impossible for a whole series of possibilities which opens the reduction in scale of the original, as for example the production of merchandising perfectly adherent to the original artwork.

Today it is instead possible to obtain the three-dimensional digital model of the artifact of interest through photogrammetry, without any physical contact between the artwork and the gripping tools, and then making a print of the same on the desired scale, which as seen was impossible with plaster casts where the scale was necessarily 1:1, obviously printing of large models is difficult and economically inconvenient.

3D printing can be based on two different CNC (Computer Numerical Control) applications:

• Subtractive printing: printing is by subsequent deletion, usually milling or selective laser, of layers or pieces of the material to be modeled, it represents the required choice to make elements in steel or aluminum at present. However, it allows the creation of prototypes with materials having a greater mechanical strength than those used in additive printing, but on the other hand it has important limitations in the printing of elements with a complex geometry.

• Additive printing: which is a print in the strict sense, it is based on the subsequent overlapping of layers of extruded material, which allows prototypes to be obtained, even with a very complex geometry, in a relatively short time and if

desired consisting of two or three different materials. Naturally it prints with materials that can be extruded, such as clay, PLA, ABS, and the like, which therefore have a lower mechanical strength, although in recent years it has been possible to print the Nylon, thus overcoming this problem in part.

The applications of a similar technology in the field of cultural heritage are not limited to the production of realistic copies, but they are multiple applications, in fact it can be used for:

• making copies to be exhibited temporarily or permanently, for example to temporarily replace a piece subjected to restoration or to definitively replace a work of historical or artistic interest that is undergoing excessive degradation due to exposure to atmospheric agents;

• we can think of support for blind people, who need to "touch" a work to be able to appreciate it, which otherwise would have no way of appreciating much of our artistic heritage;

• the mass production of merchandising that corresponds to the original work, so of certainly high quality as well as having a didactic value;

• installation of sensors, which if connected to the AR can offer visitors a more immersive and complete experience while visiting our artistic heritage;

• realization of exhibitions with 3D printed pieces; for example with the display of works that for structural or conservation reasons cannot be exhibited or transported;

Furthermore, it is also possible to use this technology for the restoration of a previously damaged work, since in fact it is possible to digitally model a missing or damaged piece of the original work, print it with suitable material and then mount it on the original artwork with a final aesthetic effect will depend exclusively on the materials and the definition chosen. We have made use of the same to verify that the print quality is such as to allow the production of elements suitable for the production of merchandising and the possible application of the same technology for the temporary replacement of an artworks.

The printer used to produce the Bronzed scale model is a "Bq Hephestos 2" which for the realization, or rather the printing, of the object exploits the subsequent deposition of layers of molten material or FDM (Fused Deposition Modeling).

It is a single-extruder printer for which it was possible to print with a single material at the time, the material chosen to print the model was polylactic acid (PLA) which now represents a standard for printing through this technology thanks to its relatively low temperature of fusion (starting from 180 ° C), to its low retraction index, to the discrete mechanical properties, but mainly because unlike the ABS, its predecessor, it does not release toxic fumes during the extrusion operations.

The software used to translate the three-dimensional model into commands in G-Code, that is the programming language of the CNC, those codes and commands that position the extruder and start to execute the print, was Repetier-Host produced by Hot-World GmbH & Co . KG, a German software house that distributes it as "free to use".

The first operation was to verify the integrity of the three-dimensional model, namely the absence of damage, gaps or cuts in the mesh and above all its structural integrity.

The first is only a necessary verification (the object must be manifold) to obtain a model that can be printed without problems, an operation that the software automatically performs and could even solve by itself without excessively altering the final result. This control is necessary because in the case in which the object we want to print is not manifold, the slicer is not able to design the printing path since it would be found with an open and not closed three-dimensional model, as is expected instead.

In this regard, we have verified that the repair carried out directly by the software is fine for minor imperfections which are therefore not appreciable when the printing is completed, while for problems related to the closure of the relevant model, better results are obtained by performing the repair manually through third party software.

The second is almost always solved by the software and concerns the need to create some supports for the suspended parts of the model, these supports are indispensable since in FDM printing operations a layer at a given height from the base is printed all at once so if we have to print a suspended piece, like the arm of Bronze A, the printer would extrude the filament on the void with the obvious consequences. Naturally these supports will then be eliminated subsequently in a mechanical way through special pliers, in the case in which it is not possible to mechanically remove the supports the best results are obtained with printers equipped with double extruder, which can print the model in two different materials, for example the model is printed in PLA and the supports in HIPS (High Impact Polystyrene) which is soluble in the D-Limonene a volatile hydrocarbon4, and then by immersing the model in the solvent the supports "melt" on their own.

Once the integrity of the model has been verified, it is possible to proceed with the Slicing that is with its subdivision into a series of "slices" (in English it is generally translated as "layer", layer) horizontal planes, which will then be extruded one above the other, by depositing molten material, from the printer extruder.

The final object will be found a slight horizontal scoring that can be reduced by reducing the printing speed (in particular on the external perimeter), the height of the layers and the thickness of the hot-end, if we want to eliminate it or reduce it to a minimum already in the printing phase, or we can proceed with the post-print abrasion of the PLA model using sandpaper or sand.

Similarly to what we saw for the external perimeter we can define the type of Infill or filling of the model. Since there are no reasons to completely fill the extruded PLA model, it is used to fill with geometric motifs, so that Infill directly affects the mechanical capacity of the final object. In our case, to get good mechanical skills we made use of an Infill Honeycomb that has excellent mechanical capabilities and does not go too far in prolonging printing times.

The software that allowed us to define the above is Slic3r, it is one of the internal slicers in Repetier Host released with an Open Source license that effectively transforms the three-dimensional model into instructions that can be understood by the printer (G-Code). The printing time required for our model was 5h and 30min and we used 23.74m of PLA.

Table-I: printing parameters

| Quality	Layer height	0.2 mm
	Wall thickness	1
Shell	Upper/lower layer thickness	1 mm
Filling	Filling density	20%
	Fill Configuration	Honeycomb
Material	Printing temperature	200 °C
	Type material	PLA
	Filling speed	80mm/s
	Support speed	60mm/s
Speed	Displacement speed	100mm/s
	External/internal wall speed	40mm/s
	Initial layer speed	30mm/s
Support	Support positioning	In all necessary point
	Overhang angle of support	50°
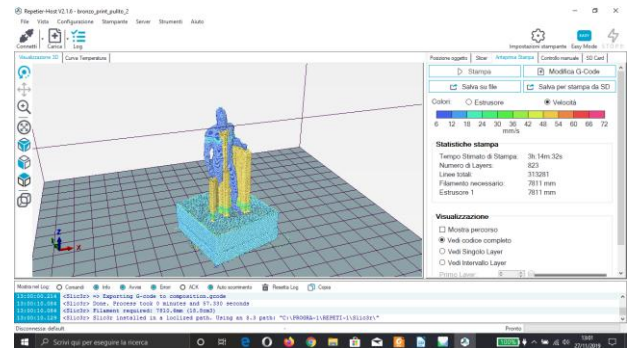
Fig. 6. Museo 3D model

Fig. 7. 3D print

III. INTEGRATION OF 3D MODELS IN VIRTUAL AND AUGMENTED REALITY

Virtual reality (VR), by its very definition, simulates reality. The advancement of computer technologies allows us to navigate in photorealistic settings in real time, interacting with the objects present in them6 . Even if at the theoretical level this simulated reality could interact with all five human senses at present it is possible to use it on a large scale only for hearing and sight.

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In fact it allows you to immerse the user in a completely simulated world with which it can interact via sensors or taps on the smartphone screen.

The most interesting application of this technology, at least as regards cultural heritage, is the simulation of realistic environments such as a virtual tour inside a museum or a work of particular historical or architectural interest, perhaps with a guide that tells the story of the artworks on display as we move within the virtual environment. While for augmented reality (AR), or reality mediated by the computer, we mean the enrichment of human sensory perception by means of information, generally handled and conveyed electronically, which would not be perceptible with the five senses7 . Museums today play a particularly important role in modern society, as they preserve events of the past and present them in a way that can be understood and appreciated by a modern public. From this point of view, the AR represents a tool with great potential, given that nowadays the visitor is no longer satisfied with an analogical experience but wants to accompany it with a digital experience that the AR can offer by representing a point of connection between the two experiences. To make use of this technology the hardware through specific sensors and algorithms determines the position and orientation of the camera and the AR superimposes 3D models on what the camera sees, essentially superimposing data or images on the real. And it is here that the real potential of this technology is captured, in fact through the AR we can observe a work, such as a painting or a sculpture, and see the same in motion or the artist who created the work explain to us why of a certain stylistic choice or tell us his story. And it is navigating in this direction that many museums have understood how the use of AR and VR allows them to offer visitors a much more immersive experience than traditional and that places the user-visitor at the center.

Fig. 8.View 3D model in Augmentaed Reality

Of course this is to the advantage of both actors in the game, in fact if on the one hand the visitors see themselves placed at the center of the visit, at the same time the museum or the authority that takes care of the realization of the app increases engagement and at the same time obtains important information on user preferences by evaluating their interactions with the various exhibited works. Precisely because of the potential inherent in these technologies, museums are proving to be one of the most interesting sectors in which to apply them, in fact through the integration of 3D models in augmented reality environments museums can offer a vision of history richer in information and much more interactive. In fact, through AR it is possible to add virtual elements to the physical reality, elements that are not limited to appearing on the screen but interacting with each other and with the user in real time, providing information on the artworks observed and providing the user with choices on how the continue the visit, it is these virtual elements that allow us to guarantee a much more formative and immersive experience for the user, but above all they place it at the center of the experience, in particular if they allow it to share the same via social media. The use of AR is not limited to museums but can be extended to the entire artistic heritage of the city, in fact it is also possible to implement it on the external cultural heritage, perhaps with references to works present in the museum, and thus allow the visitor to do not end your experience once the visit is over. Furthermore, the use of VR, which as we have seen is the user's immersion in a digital world, can allow the fruition of the works inside the museum through the creation of a digital model of the same with three-dimensional models inside, captured through photogrammetric techniques, of the exhibited works and not only. In fact, in a physical structure space is limited, so most museums cannot exhibit all the artworks they own but must necessarily choose some, in a virtual structure we do not have this problem so that the entire collection owned by the museum can be exhibited and for increase the influx of visitors to the institution, invite the user to visit the same when the work is exposed through notifications on the smartphone screen. But the possibilities offered by virtual reality also allow us to reconstruct environments of historical interest, regarding the exhibited works, which the user could visit in VR and receive information on them from an audio guide. In this regard, to favor the development of the territory it can be interesting to combine the AR and therefore push the visitor to go to the place where a certain event occurred and through the camera of their smartphone interact and watch particular micro-events or historical-artistic accurate reconstructions to an area or some historical events. One of the most interesting applications of this integration between AR and VR is the possibility of creating events related not only to the space, the place where the user is located, but also to the time. For example, it is possible to create an event that can be viewed through AR only if you are in a specific place at a specific time interval, of course this type of operation is very marketing oriented and would mainly serve to push the interest of users of the museum towards particular places or events of historical interest.

Fig. 9. App view

IV. THE DEVELOPED APP

Internet, social networks, apps are now the preferential information channel for art tourism, in fact it is through them that the travel is organized, museums and works to be visited are chosen and more and more often the tickets are purchased. And it is in this context that a tourist app for mobile devices (still under development and updating) has been created that allows the user, in real time, to view the 3D AR model of the object of interest, to have further information on the same and to buy a three-dimensional PLA print. The app, in addition to exploiting the possibilities offered by AR and VR, wants to combine these technologies with the opportunities offered by 3D printing, that is, it has been designed to allow visitors to request the printing of miniatures of 3D models of some works but not only, in fact, it is possible to reassemble the findings in virtual reality, to entirely reconstruct the missing parts, to view the original model and finally to modify, even with a certain freedom, the same and at the end to request the printing for each of the final results offered by these possibilities . Obviously, in the most classic meanings of VR, it allows you to take a virtual tour of the museum as a passive spectator or allow the visitor to be accompanied during the visit by a virtual guide that interacts with the surrounding environment. In view of a broader tourism development project in the city of Reggio Calabria, the Geomatics Laboratory of the Mediterranean University is implementing (with the Unity3D platform) an application for tourism and educational purposes, for mobile devices, which allows users to take information, written and multimedia, concerning different points of interest in the city (squares, sculptures, churches and museums using AR technology). The app is currently being defined and allows users to access different services based on the choices previously made, and in the future we hope to add tags linked to the position, so as to offer a series of services related to the place where you are there, and at the time so we can also offer event marketing oriented. In particular, in the National Archaeological Museum of Reggio Calabria, the app is able to: • show different information, concerning the history of the artifact, depending on what the smartphone camera is capturing in that moment; • display the multimedia content, such as video or audio, associated with the object framed by the user through their device; • highlight the details of interest directly on the object that we are framing and of which we want to carry out a more detailed study, making learning easier and immediate; • view the 3D model of the artifact, modify it or disassemble and rebuild it • making a virtual tour of the museum as a passive spectator, or take the same tour but as an active spectator interacting through the screen of your device; • offer the user a virtual guide that accompanies him during the visit of the museum and relates to the surrounding environment; • display the visitor's position in the museum's floor plans with the names of the rooms in which you are located; • reconstruct and assemble (even imaginatively) one or more three-dimensional models and then book a 3D print;

The app, which as said is made with Unity 3D, is structured through a series of scenes. Precisely we have an initial scene, a loading scene and an exploration scene, whose sequence depends on the choices made by the user. The two main scripts are the SceneManager that performs the initialization operations and the SceneLoader that loads the desired scene and controls the transition between one scene and another. Being the app, or rather its project, conceived as a series of scenes that follow one another over time, the first part of the work focuses on the creation of the basic elements of the virtual tour, that is the main scene containing all the information on the immersive environment we want to create. At this point it will be understood how the virtual tour is conceived as a sequence of scenes presented in succession during the passage of time, creating what is the sensation of movement. Motion tracking allows us to activate animations or videos based on the position and orientation of the device, move around an object and interact with it as if it were part of the environment and allows also to track the position of the device in relation to the surrounding environment. This type of tracking has already been implemented in our app, as it allows you to let the app know when we move and react accordingly, in order to achieve this we must make use of ARCore, a software development kit made by Google that is implemented within the Unity environment To obtain the desired result ARCore receives information from the room and from the inertial sensors present in the hardware on which we run our app and through a process called Concurrent Odometry and Mapping (COM) is able to determine the position of the smartphone that moves in space and correctly render the three-dimensional model in AR in such a way that it looks realistic, autonomously defining plans and feature points to identify the appropriate constraints for the correct positioning of the object in space and with respect to the camera. In essence, it allows the smartphone to understand where it is in relation to the world around it, and once the location of the device is known, ARCore is able to position the objects in such a way that their interaction with the environment is realistic and the device. It is also able to observe the surrounding light and illuminate objects as if they were part of the environment. We performed the test on Unity 2019.2.13 and with ARCore SDK for Unity 1.13, to make use of this package we loaded it into the Unity environment and we enabled its use from Player Settings> XR Settings> ARCore Supported and disabled the Auto Graphics API from Player Settings> Other Settings> Rendering. After that we imported the three-dimensional model inside the scene, defined the laying position (Center Eye), in order to obtain the desired effect inside the GameObject MainCamera, we added the components Track Pose Driver and ARCore Session, configured the same and finally defined the Background as an ARBacground so as to see the object inside the device as if interacting with the surrounding environment. As we want to make the experience as realistic as possible and at the same time increase the engagement of the user, we realized that the user may want to pause the experience and then resume it later, as putting the experience to rest and then resuming from scratch it can greatly reduce the user's interest. In order to achieve this we can make use of ARCore's short native break, but for our purposes we needed something different so we tested the following script:

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```
using System.Collections;
 using System.Collections.Generic;
using UnityEngine;
using GoogleARCore;
public class PauseAR :
MonoBehaviour
{
public ARCoreSession
SessionController;
private bool m_sessionPaused = false;
public void TooglePauseMode()
{
if (SessionController == null)
{
return;
}
SessionController.enabled = m_sessionPaused;
 m_sessionPaused = !m_sessionPaused;
 }
 }
```

That makes an image appear full screen during the break and allows you to pick up where you left off. We have considered it necessary to proceed in this direction rather than making use of ARCore's native pauses because these last ones force the user to resume the reproduction of the entire scene from the beginning for a medium-long pauses as can be a phone call. Using a Remote Position Call (RPC) function, we are able, based on the contents of the buffer, to make the object in question perform an action defined for a predetermined event and this action is performed both on the object present in the client than on the one present in the server.
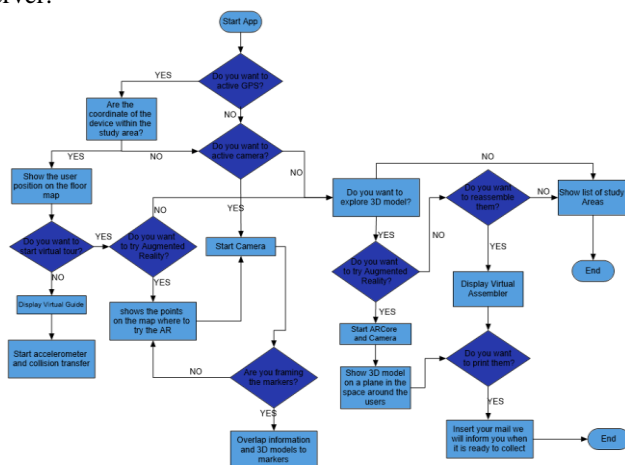

Fig. 10. Flow chart app

V. UPGRADES PLANNED FOR THE APP

Currently we are developing some upgrades to be implemented within our app. The one of the most immediate implementation and currently being studied is the possibility of offering to the user a choice of the material with which to print his model and we are evaluating the possibilities offered by: • Metal Filaments: it is a mixed filament consisting of PLA and metallic powder, often of copper, which allows to have a print with a metallic appearance which is of a higher quality than plastic; • Laywood: a filament made of 40% recycled wood that offers a final product with an appearance equivalent to that of a wooden product; • ASA (Acrylonitrile Styrene Acrylate): whose structure makes it suitable for prints that are required to be exposed to atmospheric agents, to UV rays, require a certain thermal resistance and you want to keep the color over time; • Clay: it is a print always based on the CNC but requires a special printer that is able to directly extrude the clay, of course the final result is more valuable than that obtainable with the classic print using thermoplastic polymers; Another important upgrade concerns the implementation of 360 ° videos inside the VR in order to do this we are testing the shader produced by Toulouse de Margerie and uploaded on GitHub at the link https://github.com/Unity-Technologies/SkyboxPanoramicShader. Through the use of this shader it is possible to make Unity support video at 180 and 360 degrees in equiangular layouts (longitude and latitude) or cubemap (6 frames). Of course it will be necessary to make Skybox-PanoramicBeta.shader available in the project resources and inserting SkyboxPanoramicBetaShaderGUI.cs in a resource subfolder called "Editor". Conceptually we can make Unity process a 360 ° video through the following steps: 1. Set the Video Player to process the video file as Render Texture 2. Set a Skybox Material to receive the Render Texture 3. Set the scene that will use the Skybox Material The part of the code that actually represents the heart of the shader is the following:

```
#ifdef _MAPPING_6_FRAMES_LAYOUT
inline float2 ToCubeCoords(float3 coords, float3 layout, float4 edgeSize, float4 faceXCoordLayouts, float4 faceYCoordLayouts, float4 faceZCoordLayouts)
{
float3 absn = abs(coords);
float3 absdir = absn > float3(max(absn.y,absn.z), max(absn.x,absn.z), max(absn.x,absn.y)) ? 1 : 0;
float3 tcAndLen = mul(absdir, float3x3(coords.zyx, coords.xzy, float3(-coords.xy,coords.z)));
tcAndLen.xy /= tcAndLen.z;
bool2 positiveAndVCross = float2(tcAndLen.z, layout.x) > 0;
tcAndLen.xy *= (positiveAndVCross[0] ? absdir.yx : (positiveAndVCross[1] ? float2(absdir[2],0) : float2(0,absdir[2]))) – 0.5;
tcAndLen.xy = clamp(tcAndLen.xy, edgeSize.xy, edgeSize.zw);
float4 coordLayout = mul(float4(absdir,0), float4x4(faceXCoordLayouts, faceYCoordLayouts, faceZCoordLayouts, faceZCoordLayouts));
tcAndLen.xy = (tcAndLen.xy + (positiveAndVCross[0] ? coordLayout.xy : coordLayout.zw)) * layout.yz; return tcAndLen.xy;
}
#endif
```

Finally we are studying a way to use the motion tracking of ARCore to determine the position of the user in the space and therefore inside a building even without GPS. To do this it is sufficient for us to define points of known coordinates,

ideally the markers that activate the AR, and since ARCore calculates the distance between the object in AR and the user and the relative positions to give the sensation of movement and interaction of the object with the environment, we are implementing algorithms that allow us to use this distance to define the user's position within the museum..
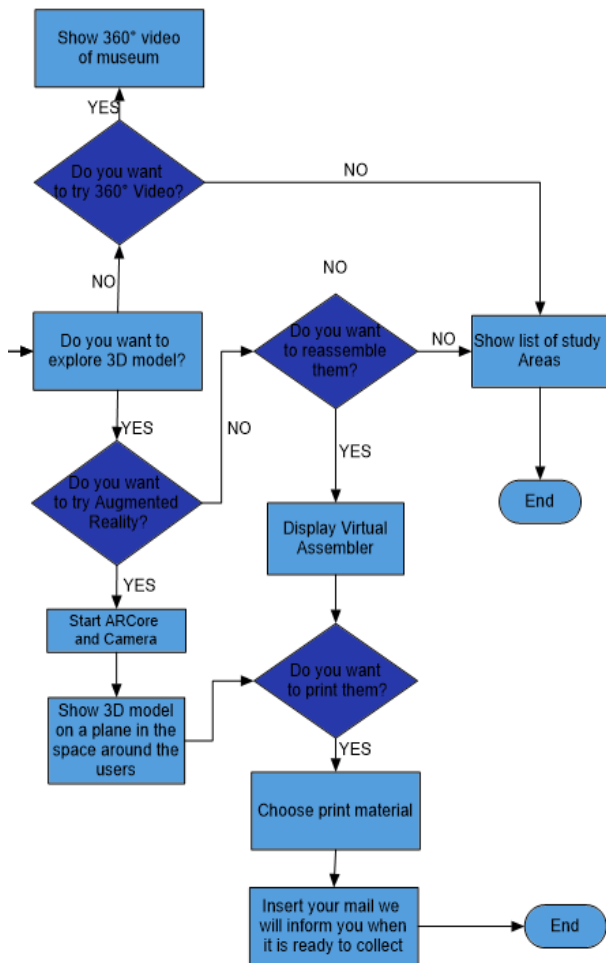

Fig. 11. Flow chart upgrades app

VI. CONCLUSION

The enhancement of cultural heritage through the use of 3D acquisition and modeling tools represents one of the fields of study that will see rapid development in the near future. In fact, new technologies, such as AR or VR, allow us to further enhance our cultural heritage and at the same time completely change the experience of its use. In particular, they allow you to enjoy an experience that is developed on multiple levels, there will be the real level or the vision of the work inside the museum, but there will be one or more levels of use of the same provided by the AR that we allow access, by observing the work through a smartphone camera, to a quantity of information, through videos, audio or three-dimensional reconstructions, which it would not be possible to provide otherwise. At the same time VR allows us to digitally reconstruct entire works and environments, thus allowing museum visitors to view works that may not be displayed at the time of the visit. So the visitor passes from a passive user, who is limited to enjoying the vision of the work or at most the support of an audio guide, to an active user whose choices influence what he sees, the paths to follow and the type of use

by offering therefore an experience full of sensations and always different. Of course, these technologies go perfectly with social media and therefore allow the user to share the experience through social networks, so he can share the paths, his own opinions and maybe discuss them with other users who have enjoyed the same service by sharing opinions and sensations. In this way the user-visitor is placed at the center of the experience, therefore he will live a unique and experience modeled on his choices and interests, consequently a user more interested in the history of the artwork will be able to deepen the same, while another user interested in the techniques used to make it can follow a different path that allows him to understand how it was made. The proposed app, still in the process of improvement and development, is designed to be a tool that moves in this direction, which can therefore be used both by experts and by simple enthusiasts interested in looking at the city and its artworks from a different point of view.

The combination of geomatic techniques for three-dimensional reconstruction, 3D printing and virtual/augmented reality is therefore an excellent solution for conservation both in metric terms and for the dissemination of the cultural heritage of which in recent years the value has been rediscovered.

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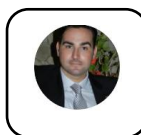
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