

Accessible Digitisation and Visualisation of Open Cultural Heritage Assets

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Figure 1: Set of open Cultural Heritage assets from the Modern period situated in public spaces the city of Rio de Janeiro (Brazil)

Abstract

*In this research, we proposed a methodology for documenting open and medium-large scale cultural heritage assets. By open we mean both in the sense of their location in open spaces and the fact that they are openly accessible to the public. We take advantage of the maturity of 3D digital technologies for enabling communities across the world to support the documentation of Cultural Heritage (CH) assets that are accessible to the public. For the present project, we focus on producing **digital replicas** of public sculptures from the Modern period situated in public spaces in Rio de Janeiro. We propose the adoption of an open-source pipeline, based on photogrammetry, which is implemented in separate phases: identification, data acquisition, processing, evaluation, and access. These phases present various challenges, in particular given the medium-large scale of such assets and the variety of spaces in which the assets are located including open spaces and other locations in which it is difficult to control the digitisation conditions. The evaluation and access of the resulting documentation is a key component of such projects. We suggest that community-led approaches have the potential to generate digital resources that are relevant both for professionals and the general public. We discuss various options for access, such as web-based solutions, Augmented Reality (AR) applications, as well as 3D printed digital replicas.*

1. Introduction

The use of visual digitisation technologies, such as three-dimensional (3D) digitization technologies, for documenting Cultural Heritage (CH) assets has acquired greater prominence in recent decades. Efforts to document tangible heritage including imaging, editing, 3D modeling and fabrication technologies are now commonplace both within heritage organisations and by members

of the public. If these efforts are continued in a sustainable way, they have the potential to enable the systematic documentation, analysis and reproduction of the spatial-temporal information related to the shape and material properties of an artifact. In this research, we propose a methodology for documenting *open* and *medium-large scale* cultural heritage assets. By open we mean both

in the sense of their location in open spaces and the fact that they are openly accessible to the public.

The Cultural Heritage community is starting to acknowledge the ability of the public to become involved in the documentation effort of heritage assets. Community-led approaches in CH are not new and some sectors, such as archaeology, traditionally rely on volunteers to enable the sustainable documentation of heritage artefacts. In the case of heritage assets placed in public spaces, it is argued that community-led documentation approaches can enable to connect communities and their heritage; while providing sustainable approaches for documentation which can support preservation and conservation of these assets.

We observe that 3D digitisation efforts have focused mainly on archaeological, pre-19th century art works and other iconic artefacts such as sculptural works. From a heritage perspective, we point out that there remains a lack of focus on more contemporary objects, such as modern and post-modern sculptural art. These objects usually present a variety of additional challenges given both by their physicality and by the recent period of their creation.

The main contribution of the present paper is a trailed methodology which is based on an open source photogrammetry pipeline. The pipeline is implemented in separate phases: identification, data acquisition, processing, evaluation and access. Special emphasis is given to the use of appropriate standards for public access and long term preservation. Additionally, the methodology addresses the need of suitable intellectual property rights related to art works produced in the last century, which have an extra layer of complexity due to authors rights related to the actual art work.

This paper is structured as follows: in Section 2 previous work on existing digitisation approaches and other issues related to open heritage assets are highlighted. In Section 3 we overview our proposed methodology for identification, digitisation and access of open Cultural Heritage assets. In Section 4 we detail the identification phase for the case of the open public sculptures from the Modern period situated in Rio de Janeiro (set of digitised assets illustrated in Figure 1). Section 5 proposes a digitisation strategy as well as an open source processing pipeline for producing the 3D digital replicas followed by the quality evaluation of the replicas discussed in Section 6. In Section 7 we discuss various options for access the digital replica, such as web-based solutions, Augmented Reality (AR) applications, as well as 3D printed replicas. Conclusions and future work are addressed in the last section.

2. Context Overview

A **3D digital replica** is a digital asset that reproduces as extensively as possible the visual information of a physical object including its shape, colour and texture information. These assets are of great use to the CH community as they can facilitate the sharing of information which is critical to the safeguarding and dissemination of such objects. As posed by Scopigno et al. [SCD*17], the progress from optical systems, digital photography, and visual computing has made available a number of mature technologies for producing **3D digital replicas**, ranging from expensive scanners to off-the-shelf cameras.

Furthermore, Web-based approaches have already revolutionised

the type of access to the result of digitisation efforts [PCD*15, SCD*17, PCDS18]. Web-based repositories, such as Sketchfab [Ske] and Scan the World [MyM], facilitate the ability to share the 3D information with a wider audience; hence, motivating a variety of users to engage in digitisation efforts.

In the last decade, a large number of projects have targeted the digitization of iconic single or set of artefacts. For instance, projects such as the 3DPetrie [Musa], STARC [STA], and 3D-ICONS [DI], among others, have investigated the application of 3D technologies for CH documentation. Scopigno et al. [SCD*17] summarize the state-of-the-art challenges for these current digitization initiatives. One important remark is the fact that despite the availability of sharing platforms, there is still a lack of an organised approach for generating and aggregating the results of the vast amount of 3D digitization initiatives. This includes the resulting **3D digital replicas** as well as all the content generated during the digitisation process.

Of relevance, is the increase of initiatives where communities participate in the digitisation process. Community-led approaches drive upwards the amount of digital content generated for heritage assets by digitisation initiatives. Kaminski et al. [KRA*12] discussed the advantages of the adoption of crowd-sourcing approaches in terms of cost and accessibility in comparison to other approaches. They concluded that this type of approach is more appropriate for mass digitisation of large numbers of objects which are accessible to the public; while highlighting the need to carefully guide the participants in the process in order to minimize variability in the quantity and quality of the process.

Our focus is on outdoor sculptures, placed on roads, streets, parks, and other public areas. This sole fact poses several restrictions on the data acquisition set up. Dimensions, placement, weather and natural lighting conditions restrict the technology eligible to be used for digitisation. We highlight two recent projects focused on open CH assets with significantly different data acquisition approaches. The first is the photogrammetry based ART UK [UK] project, an initiative on digitising public sculptures engaging volunteer photographers for the data acquisition phase; the produced 3D digital replicas were not made available to the public yet, but will probably be soon once the call for volunteering was launched last year. Another example is an initiative in Uruguay, *El Archivo Nacional de Patrimonio 3D* [FMN], for a large digitisation campaign of public sculptures in the country. The data acquisition, in this case, was made by three professionals using a hand-held scanner. Furthermore, pipelines with open source software are proposed for digitisation of a variety of heritage assets [KAP*08].

In the present work we take forward such research agendas by investigating and validating workflows which enable community-led approaches for the identification and documentation of open heritage assets. By being in public spaces, the monuments become open to the public developing a joint sense of ownership and responsibility to look after them. We also join the debate on copyright issues related to the ownership of any resulting digital content. These issues can often cause mistrust of the technology by those stakeholders who have vested interest in the assets themselves. The control over the produced content uses is a barrier to the full-scale delivery [SCD*17, Cor13].

The present research project is being hosted by the FGV/CPDOC

[FGV], which is the center for research in the Social Sciences and Contemporary History from Getúlio Vargas Foundation located in Rio de Janeiro. The city of Rio de Janeiro was founded in 1565 by the Portuguese. From 1763 until 1822, it was the capital of the State of Brazil under the Portuguese Empire. Rio de Janeiro subsequently served as the capital of the independent monarchy, the Empire of Brazil, until 1889, and then as the capital of a republican Brazil until 1960, when the capital city was transferred to Brasília. As the capital city, Rio was the scenario for many urban interventions and place for several public monuments. From 1889 to 1960 the republic's capital city was subject of several urban interventions designed to reflect the political changes; the public monuments started to reflect the aesthetic of its time. Brazilian artistic scenario was rich at the time, and modernism found its own expressiveness in architecture, landscape design, art, poetry, and literature. For almost a century, Brazilian modern and post-modern architecture and landscape design have been acclaimed world-wide. The focus on modern and contemporary history is thus justified by the target institution and the long-term goal is the interpretation of the choice and placement of the public monuments in its historic context. The technology comes as a mean to tell the story rather than the goal in itself.

3. Methodology for Documentation of Open CH Assets

The methodology proposed is based on the combination of expert and community-led efforts for the identification, digitisation and access of open cultural heritage assets. As illustrated in Figure 2 our approach is based on the premises that the objects and their context metadata are firstly identified using a collaborative approach. This can make use of participatory approaches [RJW18] where experts and community members come together to identify what is heritage, both living and historical heritage, and the relevance to the communities.

A further consideration should be given to the rights to digitise and provide access to the data. Copyright is the right to copy and publish, including in digital form. Specific intellectual property laws in each country must be taken into account as the rights of the object themselves can be subject to different considerations. For instance, works of art are protected by copyright laws for 70 years from publication both in the European Union (EU) and Brazil. However, there is an unconditional copyright exception in many countries for architecture and sculpture placed permanently in public places [LIB*15]. This exception is known as the Freedom of Panorama (FoP) provision in the copyright laws. While this exception is available in Brazil, there is not a uniform approach in the EU to adopt it. This means countries across Europe will have different protection laws.

The digitisation of the object is composed of various phases. The first is the data acquisition, that includes measuring the shape and the texture and/or photometric properties for representing the shape and appearance of the target artifact. As pointed out in the guidelines publication for the 3D-ICONS project [Cor13], non-invasive acquisition technology, such as optically based technologies, are crucial for cultural heritage applications. Among the options on optical based technologies, photogrammetry is the one based in off-the-shelf cameras, thus, expanding the range of eligible members

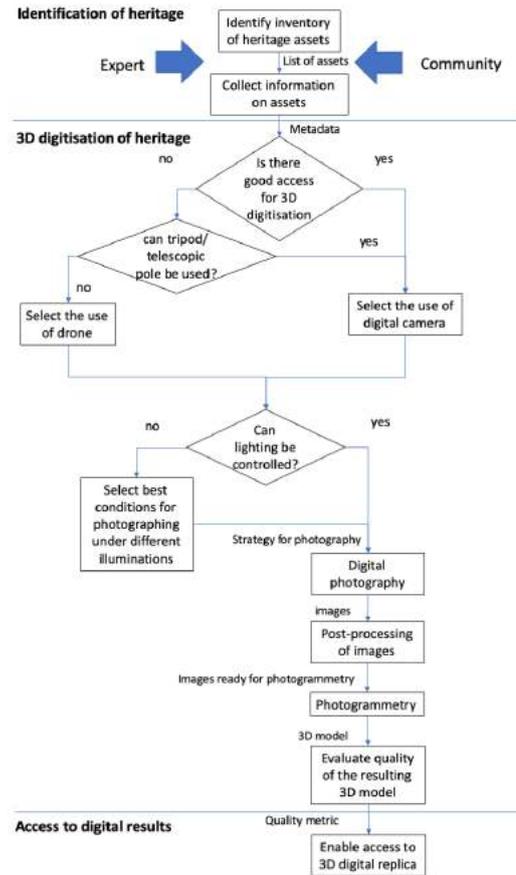


Figure 2: Workflow for the documentation of open CH assets

of the community capable to engage during the acquisition phase of the digitisation. A complete pipeline based in photogrammetry was validated in the context of 3D-ICONS project [GBG13]. Cultural Heritage Imaging [Cul] also offers comprehensive guidelines for photogrammetry and offers professionally calibrated scale bars for highly accurate measurement during scientific photogrammetric imaging of 3D data.

During the acquisition phase, it is important to develop a strategy which takes into account issues related to access and lighting conditions. Appropriate strategies, such as the number and angles from which the images will be recorded, can ensure comprehensive coverage of the object. For instance, if a tripod cannot be used then there might be the need to deploy a drone or, if not possible, seek access from nearby buildings.

The second phase is the processing of the acquired data for producing the digital replica of the shape plus appearance encoded as a 3D model. This normally involves the use of photogrammetry software. Remodino et al. [RNTM17] provides a detailed comparison between commercial software able to automatically process image datasets for 3D reconstruction purposes. However, they do not extend this review to include open source solutions.

In this research, we propose the use of a processing pipeline using only free, and preferably open-source, software. We also noted that, even though some commercial non free solutions do offer an end-to-end solution, using a single software for the entire process does not usually achieve the best end result. The following tools and software are proposed as open source alternative to commercial photogrammetry software:

- Visual Structure from Motion (VisualSFM) [Wu, Wu13]: Structure from Motion open-source software using mostly results from research articles.
- Regard 3D [Hie]: Structure from Motion open-source software
- Meshroom: part of the AliceVision Photogrammetric Computer Vision Framework which provides a 3D Reconstruction and Camera Tracking algorithms [MMM12].

Other tools which are useful in the process include CloudCompare [Clo] and Meshlab [CCC*08] for comparing and processing 3D meshes.

Once the 3D model is produced, it is important to evaluate the quality of the resulting model as well as to document the whole digitisation process. This will ensure that both the process and its result is transparent to potential users of the data. A proposed metric should reflect the quality of the resulting shape and the appearance of the object with respect to the original.

Some photogrammetry tools offer the option to calculate a metric known as the *re-projection error*. It consists of the distance between a point on the image where a reconstructed 3D point can be projected and the original location of that 3D point detected on the image used as a basis for the 3D point reconstruction procedure [Agi18]. Remodino et al. [RNTM17] offer various potential measurements which could be used for quality. They include metrics such as accuracy, precision and reliability.

With regards to the quality metrics for the appearance of the object, there is a current lack of possibilities. Pal et al. [PTW13] proposed a metric based on minimum resolution expressed in dots per inch (DPI) that takes into account local stretch and sampling density across the 3D model.

Once the 3D model is produced, there are several post-processing steps that could be used in order to transform the data into specific formats aiming to provide access to the 3D digital replicas through visualisation, Virtual Reality (VR) platforms and/or to produce physical replicas. Additionally, from the technical point of view, it is possible to adopt a wide number of solutions which combine both the digital information and physical elements from the environment bringing the discussion to the Augmented Reality (AR) context.

In the following sections we will describe the deployment of this workflow for the project on documenting public sculptures from the Modern period in the city of Rio de Janeiro, Brazil.

4. Identification of Heritage: The Modern Rio

As in most of the cities, the conservation of the public monuments and sculptures is under the responsibility of the city council and

the public policies related to its conservation are frequently a matter of political dispute and in several cases in prejudice for the monuments themselves. In the case of Rio de Janeiro, an effort led by a volunteer community member became an initiative of greater impact, it is the case of the *Inventory of Monuments in Rio de Janeiro* [Dia] produced and curated by Vera Dias, an architect working at the foundation responsible for the conservation of the monuments. She collected and published an inventory of the public sculptures, as well as curiosities based in historic sources of several monuments.

This volunteering work served as a starting point to identify of the set of monuments, illustrated in Figure 1, to be prioritized for digitisation once the available inventory was comprehensive documentation and enabled curators to make decisions with regards to the significance of the objects for the community as well as estimate the feasibility of their digitisation. The latter is of relevance, when objects are dispersed geographically and it is not possible to visit them all in order to make an informed decision.

The following paragraphs describe and illustrate the five public sculptures digitised with the proposed methodology in approximate production chronological order. The curators have prioritised this set of sculptures based on several criteria, including technical restrictions, artistic relevance, context in the city, and aesthetic considerations. The ongoing project is planned to have 17 more digitised replicas by the end of the present year.

B. Giorgi's "Juventude Brasileira": Bruno Giorgi (1905-1993) was a renowned Brazilian sculptor of Italian descent. He lived his youth in Italy and studied sculpture in Paris. In 1939 he moved back to Brazil where he produce several monuments placed in the modern sites in Brazilian cities. The "Juventude Brasileira", 6.7 meters high in granite, illustrated in Figure 3, is a representative work of his figurative phase. It was one of the selected pieces in a contest in 1943 for the gardens of the Ministry of Education and Health building, the *Gustavo Capanema* Palace.



Figure 3: Left: Picture of Bruno Giorgi's "Juventude Brasileira" sculpture. Right: Dense cloud of points processed in MeshCloud.

A. Janacópulos's "Mulher": Adriana Janacópulos (1892-1978) was a Brazilian sculptress of Greek descent. She studied and lived in Paris part of her life and exhibited her works in several artistic salons in Europe at that time. She moved back to Brazil in 1932, and

in 1938 she received a commission from the Ministry of Education and Health to sculpt a work for the gardens of the *Gustavo Capanema* Palace. She sculpted the “*Mulher*”, approximately 2 meters high, in granite, illustrated in Figure 11 and in Figure 12.

R. Burle Marx’s “Panel”: Roberto Burle Marx (1909-1994) is a Brazilian renowned architect and landscape designer. In 1937, Burle Marx gained international recognition for his abstract design of the roof garden for the *Gustavo Capanema* Palace, where the sculptures “*Juventude Brasileira*” and “*Mulher*” are located. The MoMa [MoM] and the Jewish Museum [MusB] in New York have recently run exhibits on his life’s work [Ada91]. The digitised “*Panel*” is situated in the facade of the Architecture Faculty building at the Federal University of Rio de Janeiro main campus (Ilha do Fundão). It was designed by Burle Marx in 1953 and built in reinforced concrete. The approximate dimensions are 54 meters long by 10 meters high. As an additional finding from this campaign, the use of entasis in the design of the panel could only be observed through the 3D model due to the size of the physical monument (Figure 4).

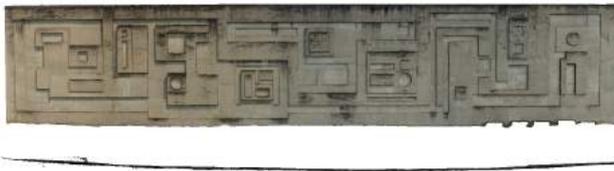


Figure 4: Front and top views of Burle Marx’s “Panel”

A. Cheschiatti’s “*Evangelista Matheus*”: Alfredo Ceschiatti (1918-1989) is a Brazilian sculptor of Italian descent. He studied at the National School of Fine Arts in Rio de Janeiro and then in Italy. Back in Rio he worked with the big names of Brazilian Modern architecture and produced several monuments for public spaces.

Originally, a huge monument of A. Ceschiatti, situated at *Aterro do Flamengo* was selected by the curators of the project to be digitized, but due to lack of permission to access the site during the duration of the first phase of the project the piece was substituted by the “*Evangelista Matheus*” situated at the *Catacumba Park*, in the city’s south zone. The *Catacumba Park* opened in 1978 and holds an important collection of public sculptures. The “*Evangelista Matheus*”, illustrated in Figure 8, is a 3 meters high sculpture made in mortar, and is in a very poor conservation state, presenting structural cracks. It is supposed to be a study for the one made in bronze for the *Brasilia’s Cathedral*, inaugurated in 1970.

S. Camargo’s “*Estrutura*”: Sergio Camargo (1930-1990) is the youngest artist within this initial set. He is situated in a later abstract period of Modernism. The “*Estrutura*”, illustrated in Figure 5, situated in the *Catacumba Park*, is one of his representative works.

5. Producing the 3D Digital Replicas

After evaluating the location of all the objects previously described, it was decided the best strategy is to use a 12 meters telescopic pole and digital cameras for photography. Hence, the digitisation used



Figure 5: View of the 3D digital replica of “*Estrutura*”.

two mirrorless cameras (Panasonic and Olympus) with nominal resolution of 16M pixels each, as well as a 24-80mm zoom lens and a 24mm fixed lens. The number of photos taken for each object is available in the Table 1. The table also specifies the approximate height of each object.

The strategy for digitisation, illustrated in Figure 6, involves photographing the monument from different heights. Typically, between four to five heights levels were used for the monuments. For each height level, 60 images or more are taken following the morphology of the object. The distances from which the photographs are taken vary depending on the level of complexity and number of self-occlusions.



Figure 6: Digitisation strategy. Left: telescopic pole is used for photographing. Right: diagram of heights for 360° acquisition

It must be acknowledged that each sculpture is unique both in terms of size and level of complexity. Hence, the quantity of images taken for each object differs. For instance, the “*Juventude Brasileira*” required 600 images in total given the size and number of self-occlusions present in the sculpture. Figure 7-top illustrates the positions of the cameras recovered from the images. On the other hand, the Burle Marx’s “*Panel*”, despite its size (54 m wide), only required 120 images - 20 from a general view (24mm) and 100 from a more detailed view (50mm) - as its geometry is fairly simple. The camera positions for the “*Panel*” data acquisition are illustrated in Figure 7-bottom.

The lighting conditions for the acquisition of objects were complex given the sunny climate in Brazil. For instance, photographing

Sculpture	Height (m)	Number of Photos	Surface Area (m ²)	Resulting Density (points/m ²)
<i>Juventude Brasileira</i>	6.7	600	44.66	27,362
<i>Mulher</i>	2	430	7.52	189,862
<i>Panel</i>	10	120	192.38	88,904
<i>Evangelista Matheus</i>	3	492	9.89	314,090
<i>Estrutura</i>	0.75	457	5.65	365,610

Table 1: List of digitised heritage assets with approximate heights and number of images taken in acquisition phase.

the “*Evangelista Matheus*” was specially challenging since the back of the sculpture is in constant shadow from the forest that lies behind, while the front is illuminated by the sun light during most of the day. Figure 8 illustrates the variability in lighting during the acquisition process. Currently, there is no easy way to solve this issues given the large scale and sometimes difficulty of access when working with monuments. To soften the lighting difference, illumination compensation of the back side images of the monument was performed manually. The obtained results are illustrated in Figure 8.

After processing some of the input images for colour correction, the data were used as input for the photogrammetry process. Different open source software were adopted including: VSfM, Regard3D and Meshroom. VSfM was used for computing an initial



Figure 8: Top: Selected images from the “*Evangelista Matheus*” photogrammetry input data set. The back of the statue is always in shadow, thus influencing in the final texture quality of the 3D digital replica. Bottom: Side-by-side comparison of rendered model with (left) and without (right) lighting compensation.

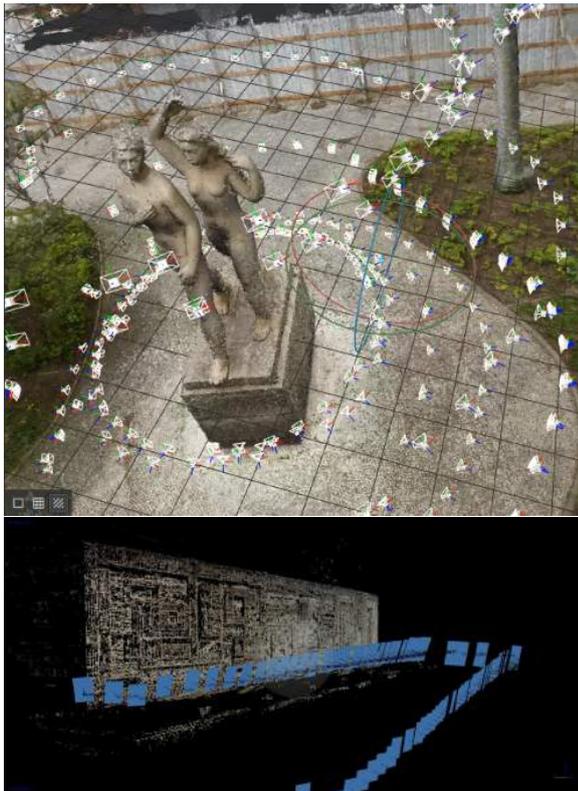


Figure 7: Top: “*Juventude Brasileira*” data acquisition camera positions recovered using Meshroom. Bottom: Burtle Marx’s “*Panel*” camera positions recovered with VisualSfM software.

estimate of the camera spatial position and orientation in order to produce the first sparse point cloud. For this, feature points are matched between cameras. The point cloud and camera positions are then optimised using bundle adjustment.

The point cloud resulting from the camera registration stage is a useful result by itself. Hence, it is possible to use other software, including Regard3D to generate a dense cloud and the 3D triangulated mesh from the sparse point cloud produced by VSfM. This combination of tools seems to produce the best outcome. Another software which was used for experimentation with the photogrammetry pipeline is Meshroom. In this case, the images were used as input and a 3D model was produced. Additional tools such as CloudCompare and Meshlab were used for manual noise removal and reconstruction to produce a watertight 3D model.

Timings for the processing of the images using VSfM, Regard3D and CloudCompare are presented in Table 2. The software was de-

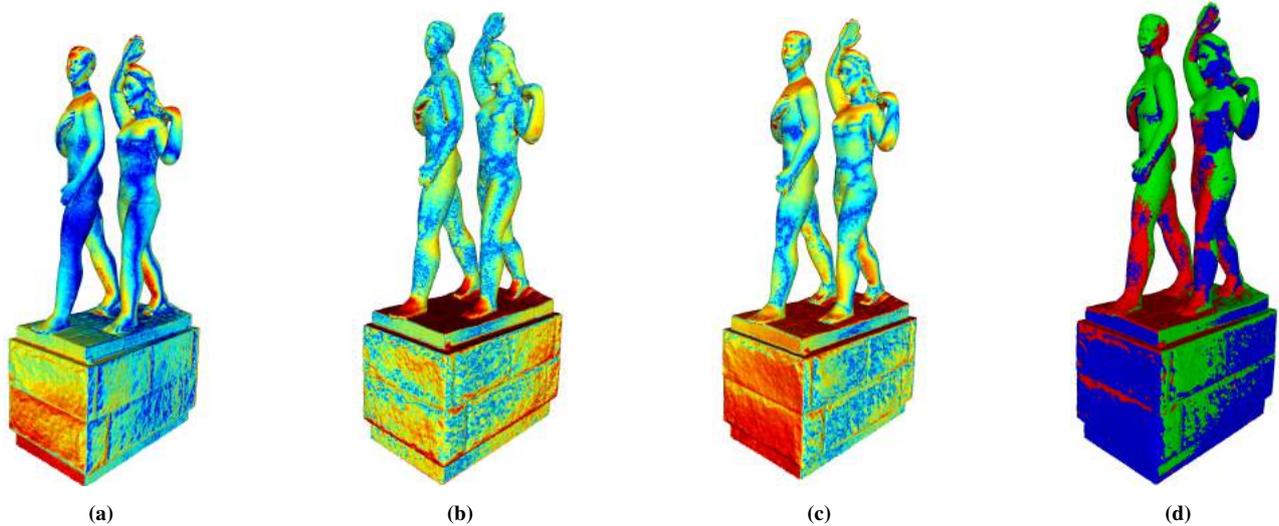


Figure 9: Comparison between resulting 3D models from open source tools produced with different open-source software: (a) Comparison between VSfm/Regard3D and Agisoft Metashape. Deviation between the two models has a maximum of 0.028697, a mean of 0.005696. (b) Comparison between Meshroom and Agisoft Metashape. Deviation between the two models has a maximum of 0.049973, a mean of 0.006318. (c) Comparison between Meshroom and VSfm/Regard3D. Deviation between the two models has a maximum of 0.049613, a mean of 0.007466. (d) Overlapping 3D models from Meshroom (blue), VSfm/Regard3D (green) and reference 3D model processed in Agisoft Metashape (red).

ployed on a PC with two Xeon processors, two graphic cards GTX 1080 and 256 RAM. As shown in the table, both the camera registration and dense point cloud generation take the longest time in the process, with the models taking between 2 - 10 hours to be produced.

6. Quality Evaluation of 3D Digital Replicas

The process described in the previous section produced various 3D models for the digitised sculptures. The aim of the evaluation stage is to understand how the different open source software perform when recording the datasets produced during the acquisition stage, given the various constraints posed by the assets, as well as to understand the quality of the 3D models produced.

Sculpture	Processing Times (mins)				
	Panel	Evang.	Mulher	Juv.	Est.
VSfM (a)	120	30	120	180	120
VSfM (b)	15	20	20	25	20
Regard3D (a)	240	290	180	300	180
CloudCompare	15	25	20	25	20
Regard3D (b)	30	90	45	23	45
Regard3D (c)	25	45	25	40	25

Table 2: Timings for processing 3D models in the photogrammetry pipeline: VSfM was used for (a) camera registration and (b) camera processing. CloudCompare was used for noise removal. Regard3D was used for (a) dense point cloud generation, (b) surface generation and (c) texture generation.

Initially, it is possible to compute the density of the reconstruction as the surface area is known. The density are shown in Figure 1 for each sculpture.

Although the literature includes previous evaluation efforts of the results of commercial photogrammetry software [RNTM17], these efforts did not extend to open source solutions. Moreover, Kersten et al. [PKPL*16] reported a comparison between different hand-held scanner systems and how the results compare with the results produced by a photogrammetry model using a digital SLR camera. They use four so-called “Testys” (height of 380 mm) for the bench marking test. The comparison uses as a reference two structured light 3D scan: ATOS I 2M and smartSCAN 3D.

In this research, it was not possible to 3D scan any of the sculptures in order to use the data as a reference. This is mainly due to the lack of access to a 3D scanner and for the large-scale size of the objects. For this, the commercial software Agisoft Metashape [Agi19] was used to process the images of the “Juventude Brasileira” sculpture and considered as a reference 3D model. This was selected given its scale (6.7 meters high) and its geometry. A 3D model was produced with a re-projection error of 1.03 pixels.

Given the models produced with different software, we proceed with the comparison. The visual comparison is done by means of using a color-scale to encode the distance computed between the 3D model and the reference model. The Hausdorff distance summarizes the comparison. It is defined by the greatest of all the distances from a point in one set to the closest point in the other set. Figure 9a and 9b illustrates the comparison between the two models generated with open-source tools, VSfM/Regard3D and Meshroom, against the reference model produced with Agisoft Me-

tashape. The model produced by Regard3D (feeding from cameras computed by VSfM) has some strong similarities in some of the areas (chest and legs) but stronger dissimilarities on the shoulders and head (Figure 9a). The outcome of Meshroom (Figure 9b) appears to have a more homogeneous similarity to the reference model for the two human figures with the exception of the area on top of the plinth. A further comparison is done between the results produced by VSfM/Regard3D and by Meshroom. Figure 9c illustrates some differences between both models (in red). Finally, Figure 9d presents a visualisation of the three 3D models aligned on the same 3D coordinate space.

This evaluation demonstrated that the open source software performs very close to the commercial solutions. As such, the most important aspect of the process is the quality of the images which are used as an input. Furthermore, the quality of the texture were not assessed as the tools used do not provide either metrics or information in a format useful to compare tools.

7. Delivering and Consuming Heritage 3D Digital Replicas

Although the production of three dimensional digital models have achieved a level of maturity, its delivery to the general public is still subject to wide research with a variety of solutions [PCDS18]. This includes the delivery of 3D content through a variety of platform and software solutions, including desktop PC, mobile devices, Virtual Reality (VR), Augmented Reality (AR), holographic projection and 3D printed replicas.

At present, our project delivery emphasis was on solutions useful to humanities scholars such as curators and historians. At the current stage of the project, the digital assets are being used by the scholars and not being delivered to the general public yet. Different platforms and software were trailed to this target users, both for them to access and also for envisioning future possibilities. These include: web-based visualisation, Augmented Reality (AR), orthophotos and 3D printing. Prototypes were developed for all of these applications to be tested by the scholars working on the documentation of the Cultural Heritage assets.

7.1. Web-based visualisation

In general, 3D digital replicas can be manipulated by the user through specialised desktop software. There are several options available ranging from simple visualizers to highly technical ones, like Blender and Meshlab, for instance. In late 2009, due to WebGL release, a deep change in the scene for delivering 3D models to consumers through web browsers was made possible. As browsers started to consistently support WebGL, this signified a change in the ability of users to access 3D models without the need to install software. More recently, the computer graphics community developed solutions considering the specific needs of CH sector. One such solution is the open-source 3DHOP software [PCD*15, SCD*17] for web-base visualisation, illustrated in Figure 10.

The 3D digital replicas are supposed to store the details and richness of the original master-piece. Thus, usually the models are very complex and consequently big. This is a bottleneck for streaming visualization of 3D digital replicas in browsers without breaking



Figure 10: 3DHOP Web based visualisation of “Mulher”

the user experience due to slow interactivity response. Thus, multi-resolution or LoD representations are usually required as part of the solution. For 3DHOP, the multi-resolution nexus format [PD16] is supported as a mean to cope with this demand. Additionally, multi-resolution is a form of implicit protection to intellectual property rights, once the data is never transferred or stored completely in the client. The 3D replica must be processed to be stored as multi-resolution format to be served to the client.

7.2. Using Augmented Reality

An Augmented Reality (AR) application was developed which allowed users to visualise and manipulate the 3D digital replica (see Figure 11). The application is accompanied of a narrative audio that provides the user with contextual information of the monument. The app has been developed using “Unity 3D” to run in android OS.

The 3D digital replica must be processed to produce a reduced size model with 150,000 polygons for optimized for real-time visualization. Narrative audio is recorded at 65 kPs Mono with 48000 kHz rate for little space consumption limited by the total size of the app. For instance, Google play Apps usually are limited to 100 MB. The fiducial mark placed in the environment for positional tracking for the AR application is what we refer to as a *splash image* representing the artwork, as illustrated in Figure 11. The application uses a image recognition for triggering the display of the 3D model.



Figure 11: Augmented Reality app. Left: AR “Evangelista Matheus” activated by its splash image on the screen of a cellphone. Right: AR “Mulher” activated by splash image on paper.

Overall, the augmented reality application proved to be an engaging and effective tool for the visualization and understanding of the three-dimensionality of the 3D digital replica at the same time as a powerful dissemination application.

7.3. Orthophotos

Orthophotos are one important product for documentation. An orthophoto consists of a digital image where every point of the object is strictly orthogonally projected with pixel-level accuracy. It is a powerful representation of the object that combines geometric accuracy with rich texture detail. Orthophotos are being widely used for landscape documentation even replacing maps in some contexts. Nevertheless, they are still hard to produce with enough quality to be used in architecture and conservation applications [AHF10, MNL*08], although the use of orthophotos is justified as a tool for high detail damage mapping annotation for digital monument preservation. Recently, the photogrammetry pipeline was used to produce orthophotos.

In the present case, the orthophotos were processed as high quality renderings in Metashape software. These are illustrated in Figure 12 for the “Mulher” sculpture.



Figure 12: “Mulher” orthophotos: high-resolution plan metric projection (600 dpi) obtained through High Density Close Range photogrammetry



Figure 13: “Mulher” 3D printed replica

7.4. 3D printed replicas

Another option to experience the 3D model in a tactile way is to use 3D printing in order to physically reproduce the 3D model. For this, we used Fused Deposition Modelling and stereolithography to print a 10 cm sized scaled model of “Mulher” (Figure 13 and “Juventude Brasileira”). The stereolithography used was a Form2 from Formlabs and the layer thickness is 0.1 mm.

8. Conclusions and Future Work

In this paper, we proposed a methodology for documenting *open* and *medium-large scale* cultural heritage assets. We have focused on producing **digital replicas** of public sculptures from the Modern period situated in public spaces in Rio de Janeiro, Brazil. The proposed workflow is composed of several phases: identification, data acquisition, processing, evaluation and access. For all of the phases, data is produced as well as related metadata.

We discuss various options for access, such as web-based solutions, Augmented Reality (AR) applications, as well as 3D printed digital replicas. Borowiecki and Navarrete [BN17] argue that the digitisation of heritage collections can be an indicator for innovation potential in heritage institutions. This is also true for the potential re-use of such digital content in a variety of delivery platforms.

We have provided digital access of the assets for scholars participating on the project. They can easily inspect the 3D replica and is helping them to discuss and design the delivery approach for the general public. AR and 3D printing were also useful as proof of concepts, and guides the discussion on how to meaningfully use these technologies in order to make the heritage more accessible.

The digitisation of iconic artifacts is well discussed in the literature, yet, less discussed is the challenge of community-led documentation for open collections such as public sculptures. We suggest that community-led approaches have the potential to generate digital resources that are relevant both for professionals and the general public. In this research we take forward such research agendas by investigating and validating a workflow which considers community-led approaches for the identification and documentation of open heritage assets. By being in public spaces, the monuments become open to the public developing a joint sense of ownership and responsibility to look after them.

This is an ongoing project and there is a lot of room for future directions. More sculptures are to be digitized for the project following the proposed methodology. Historians and curators are working in the context information and the links with other documentation basis aiming to enhance the storytelling of modern and contemporary urban design in Rio de Janeiro. We are also working on a system for metadata access and manipulation that could integrate the multimedia visualisation and the metadata manipulation.

Apart from the open heritage, we have also made an effort to use open software tools in our methodology. Nevertheless, since the pipeline is not fully open-source based, we argue that there is room for the development of such open-source applications. In regards to quality evaluation there is also a clear lack of available metrics for appearance (texture) evaluation.

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