Digital Mediation from Discrete Model to Archaeological Model: the Janus Arch

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Survey operations and the representation of acquired data should today be considered as consolidated. New acquisition methods such as point clouds obtained using 3D laser scanners are also part of today's scenario. The scope of this paper is to propose a protocol of operations based on extensive previous experience and work to acquire and elaborate data obtained using complex 3D survey. This protocol focuses on illustrating the methods used to turn a numerical model into a system of two-dimensional and three-dimensional models that can help to understand the object in question. The study method is based on joint practical work by architects and archaeologists. The final objective is to create a layout that can satisfy the needs of scholars and researchers working in different disciplinary fields.
The case study in this paper is the Arch of Janus in Rome near the Forum Boarium. The paper will illustrate the entire acquisition process and method used to transform the acquired data after the creation of a model. The entire operation was developed in close collaboration between the RADAAr Dept., University of Rome "Sapienza," Italy and the Istituto de Arqueologia (CSIC, Junta de Extremadura, Consorcio de Mérida), Spain.

Keywords: 3D Survay ; 3D modelling; Methodologies, Architecture-Archeology .

1. General Outline

The so-called Arch of Janus is a well-preserved quadrifons arch in Rome. It stands near the church of San Giorgio al Velabro, not far from the Temple of Hercules and the Temple of Portunus, and was built on the edge of the Forum Boarium probably in the mid-fourth century. It presumably coincides with the Arcus Divi Constantini, mentioned in the Regionary Catalogues near the Velabro. Its modern name comes from the Latin ianus, indicating a covered corridor or entrance. Like the corridors present in the spas in the Roman Forum, it wasn't a triumphal arch, but probably a building used by the bankers working in the Forum Boarium. The square plan building (12m each side, 16m high) had four massive cement pillars covered in old reused marble and supporting a cross vault.

This study was carried out jointly by architects of the Department of Survey, Analysis, Drawing of the Environment and Architecture (RADAAR) of Rome University of "Sapienza" and archaeologists of the Instituto de Arqueología de Mérida, Spain.

Figure 1: *Phtograph of the Janus Arch.*

From an archaeological standpoint, working with a group of architects was crucial to achieve a better and thorough understanding of the building. The use of 3D scanning is a fundamental tool in archaeological studies.

The accuracy of the graphic restitutions and architectural details makes it possible to carry out detailed research on structural elements traditionally ignored by general historiography.

One such case is the information provided by new surveys regarding the stratigraphic analysis of the Janus Arch. The monument has several unique archaeological and architectural characteristics. The building process is very complex, and several details of the construction and finish of the building materials would have remained undetected without a high precision survey.

Carrying out a new survey is exciting for another very important reason associated with the monument's archaeology: stratigraphic analysis. Due to the arch's location and its important role in the topography and urban planning of the Forum Boarium, it underwent extensive changes over the years, even though its overall appearance remains unaltered in those areas where its structure is intact. These changes include: the destruction of some parts of the foundation and attic; additional structures inside and outside the arch as well along the upper part of the arch, made during the Middle Ages by the Frangipane family; the neglect and demolition of the parts built during the Middle Ages; the extensive modern renovations, and the closure of the adjacent area after the terrorist attack in the 1990s.

The collaboration between the archaeologists of the IAM and the architects of the RADAAR will add new information to the traditional architectural studies carried out only from an archaeological point of view. To this end, specific methodologies will be used to record all work performed on the building over the years, from its initial construction to recent changes made to the monument.

2. Methodological approach

Up to now, the study of archaeological surfaces has posed numerous methodological, technical and operative problems regarding the actual survey and ensuing elaboration of the results.

Over the years, various systems were used to optimise the acquisition of measurements in order to obtain increasingly satisfying results, illustrating in detail both an object's geometry and architecture as well as the unique features of its surfaces.

Over the years, new methodologies were used in conjunction with time-honoured, traditional direct survey techniques: topography and analytical photogrammetry. Topography increased the accuracy of the measurements, but did not eliminate the need to acquire the millions of points needed to provide the best possible image of the surfaces. Nor should we forget the problems caused by the laborious procedures and protracted operations. Using photographs, analytical photogrammetric procedures can establish the object's position, shape and size; this allows us to identify the spatial position of the most important points of the object and turn them into measurable lines using a CAD system. The problems inherent in this system depend directly on the geometry of the objects surveyed and, above all, the elements which appear foreshortened compared to the reading (DOCCI *et al.*, 2005; 2007).

Survey was revolutionised by the advent of 3D laser scanners and data modelling. For many years, architects and archaeologists have discussed the drafting of an "operative protocol" to establish a standard procedure to process the acquired data. Past experience has shown that the best results will come from combining technical resources and intense research activities, and that only tools will actually achieve these optimal results (BIANCHINI, 2007:36-49).

This requires not only close collaboration between architects and archaeologists, but also solid synergy between their respective methodologies: between new survey techniques used by survey experts and the historical and archaeological expertise of archaeologists.

To correctly establish an operational protocol the survey concept has to be properly identified and this involves merging two separate kinds of survey: critical survey which defines the object using its geometric and architectural characteristics, and an *objective survey,* which consists in ensuring unbiased data to allow for an in-depth specialist interpretation.

The *survey* will therefore depend on two consequential but inevitable aspects: *complex 3D surveying* achieved by using a combination of different tools, and *complex 3D survey* achieved by combining different models (IPPOLITO, 2009: 76-85).

Obviously the first stage is *complex 3D surveying.* This chiefly involves acquiring the data and collecting any useful information about the object which can also be studied to acquire greater understanding and knowledge: an analytical phase focusing on collecting qualitative and quantitative data.

A combination of methodologies and tools are used during the acquisition process including topography, image matching photography and long and short range scanners.

Contrary to what happened in the past, these tools make it possible to very quickly acquire millions of points and countless images. These operations, which could be considered absolutely mechanical, actually involve long preparatory work and decisions about all aspects of measurement methods. These tools can help the operator when he has to decide how to define the *models.*

So the biggest difference between previous and current measurement methods is the quantity of acquirable data.

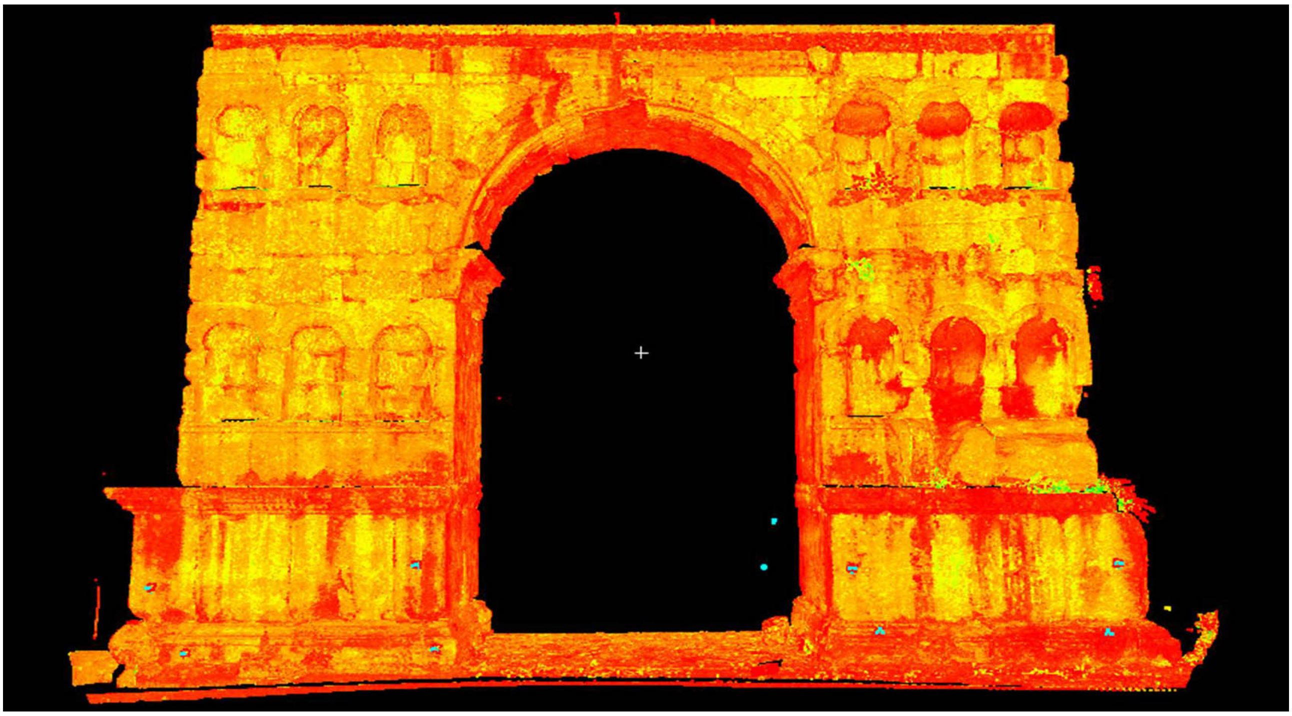

Figure 2: *Point cloud of the Janus Arch using a Laser Scanner Leica HDS3000, representations in false colours with the reflectance values of the materials.*

We should point out that 3D laser scanners cannot make selective choices: they perform mechanical operations governed by a parameter simply calibrated to acquire data. The result is a numerical model which can be used as documentary information: however, it is the basis for later operations and elaborations to turn the *3D surveying into a 3D survey.*

All 3D survey operations regarding data acquisition are naturally considered within the protocol. After developing the survey project, which provides a certain amount of leeway when planning readings of the building (3D laser scanning, topographical points, photographs), the protocol establishes strict criteria regarding which scans will be used; the latter will depend on the scale model to be developed. The more detailed the scale, the greater the need for more accurate and defined data, with both 3D laser scanner and topography.

The second step involves turning the 3D surveying into a 3D survey by *combining the models*. Both research teams concur in this regard, i.e., turning objective data (surveying) into data containing all the information required to interpret and study the building (survey).

The model concept must therefore be redefined and updated. In the digital age, the model concept is based on digital techniques now present in all architectural representation tools, techniques which have also invaded the field of architectural survey. In particular, with regard to the model, two-dimensional (2D) and three-dimensional (3D) representations have created a new kind of model no longer only static, but also dynamic. This model is able to represent, comprehend, elaborate and modify the survey; it allows us to move around it and shift from outside to inside the model using 2D and 3D elaborations in a transitive manner.

We can now have continuous interaction between the temporal and spatial elements. We can also add that complex and absolute interactivity has been created between the real object (points clouds and photographs) and virtual digital models (2D and 3D models). This incredible opportunity for interaction between what is real and what is virtual was inspired by IT systems invented to facilitate industrial production and has led to another even closer relationship between physical and digital models. The CAD-CAM systems with Rapid Prototyping methods and the possibility to acquire data using a 3D Laser Scanner makes it possible to start with a virtual image and build a real one, and vice versa, in an interactive manner; this is a seamless procedure and can be done using the same object in both directions.

Figure 3: *Detailed scansion of part of the Janus Arch. Representation in false colours with the reflectance values of the various materials.*

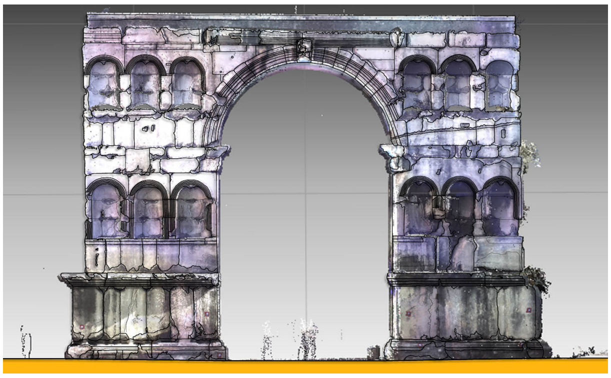

Figure 4: *Two-dimensional models of the Janus Arch characterised by a texture.*

Within the framework of the protocol we can now define the models used in the survey as: *2D models; 3D models; details*. The characteristics of each one is its scale. In absolute terms, it is possible to analyse the different models using scales ranging from 1:1 to 1:X.

A better way of explaining the system behind the 3D survey is to say that we should establish a system of models capable of creating multilevel analytical documentation.

This documentation is created by the systematic integration of the models defining and describing the object. The 2D and 3D models are characterised by: geometry, topology and texture. Considered in the Greek sense, geometry identifies the positions, i.e., the coordinates of the characteristic points defining the objects in space. Topology is considered as the definition and description of the relationships and links between the geometric entities, i.e., the study of forms. Texture is considered as a defining feature which, when applied to geometry and topology, determines the specific properties of the surface in order to make it recognisable and relat it to the original. So, on the one hand, geometry and topology define the object's two and three-dimensional geometric features and, on the other, texture characterises the former two using 2D and 3D patterns and maps. Once the object's features have been defined, we can establish the way in which the models have to represent the object on different scales.

The 2D models are defined using drawings of the geometric representation, proportioning and architectural representation. These representations are developed after registering the points clouds and the introduction of horizontal and vertical section planes. The points and lines defining the object will be created by positioning the cloud itself in parallel projections, after which the operator will select its characteristic features.

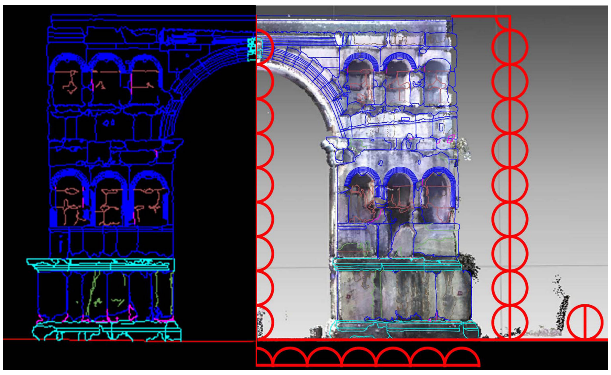

Figure 5: *Two-dimensional models of the Janus Arch after elaboration of the survey data.*

The 3D models are also illustrated by geometric representation, proportioning and texture. In this case too, 3D models are developed by creating horizontal and vertical sections. Definition of the architectural features will be determined using 2D maps and architectural representations.

The last factor in this multilevel analytical documentation consists in what we have called details. The latter includes a whole series of in-depth and specific data about the object. With all the data in hand, we can define which parts are to be studied in detail. In order to better define this aspect in the protocol we developed a layout of the details. The object is broken down into various elements, jointly agreed upon with the scholars, and includes: raw acquisition data (various formats, from the one created by the acquisition software of the 3D laser scanner and other extensions including interchange such as .dxf), i.e., without any elaboration, so that the scholar is free to recreate whatever he wants; detailed 2D and 3D models created using very dense acquisition data (possibly using short range laser acquisitions); physical prototypes, also created using elaborations of transferable, high density points clouds (e.g., epigraphs and engravings on surfaces); and finally, publisher software to put online data which can be examined from all angles and which allows the points cloud to be measured.

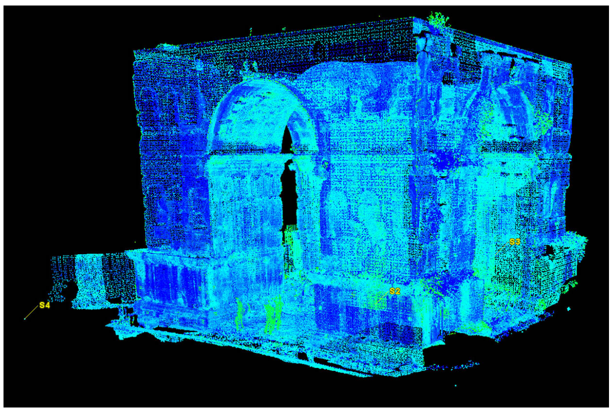

Figure 6: *Complete points cloud of the Janus Arch. Representation in false colours with the reflectance values of the materials.*

3. Procedure

The procedure used in this survey is based on studies and research carried out by the Department of Survey, Analysis, Drawing of the Environment and Architecture (RADAAR) of Rome University of "Sapienza," tested

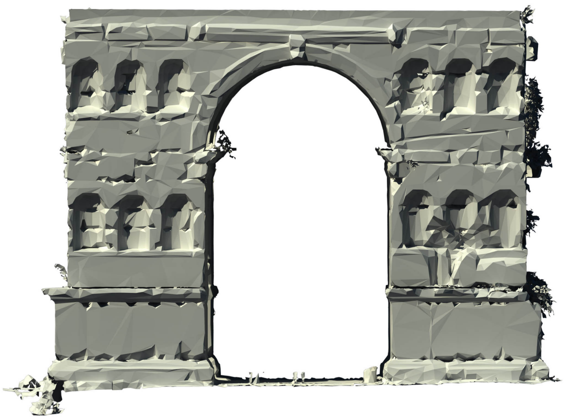

Figure 7: *Part of the 3D mesh model. Reduction by a tenth of the survey data to produce a representation approximating a 1:200 scale of representation.*

and developed during years of countless studies. It is important to stress, however, that this procedure is neither mechanical nor automatic, but requires the operator to have knowledge and know-how so that he can correctly interpret the object to be studied, and choose the right surveying and modelling operations.

The first step was obviously to plan the work. We chose to carry out an "integrated" survey and made decisions as to the specific procedures and tools required. We wanted to optimise the work and ensure exhaustive and comprehensive survey data (AA.VV., 2009).

The next step involved acquiring data and carrying out the various survey operations, using the potential provided by tools such as theodolites, 3D laser scanners and high resolution cameras. Our extensive knowledge of different surveying techniques, acquired and tested in other studies, allowed us to combine the different technologies to obtain a point cloud - the "objective numerical" model - which we could then visualise as a 3D object in a computer. Naturally, this is just a piece of documentary data, in other words, it can in no way be considered a survey, but just a useful tool with which to begin working. We were well aware that it was necessary to perform both a topographic survey and another one using a 3D laser scanner (Leica HDS 3000) because, not only were they compatible, but they would be more accurate when registering the various point clouds (in this case, registration error was less than 3mm). Once this stage - acquisition, registration, and 'cleaning' of the data - was completed, the general point cloud consisted of 23,700,000 units. Because we obtained such extensive information from the survey campaign, we had to break down the architectural object into several parts so as to work with smaller point clouds and tackle assembly only during the final stages of the study.

We created a mesh surface for each part, using suitable filters to reduce noise and ensure better data distribution. To develop 2D and 3D scale models we also limited the amount of data we used by a tenth, thereby creating 3D models with a level of detail in line with their scale of representation. This allowed us to create different scale 3D models, ranging from 1:200 to more detailed 1:2 scale models.

Once these initial "superficial" operations were carried out on the model, we performed several more invasive editing procedures on the geometry to create the final geometric 3D model. These new operations slightly reduced the accuracy of the original data, but allowed us to achieve a final result which was much more akin to

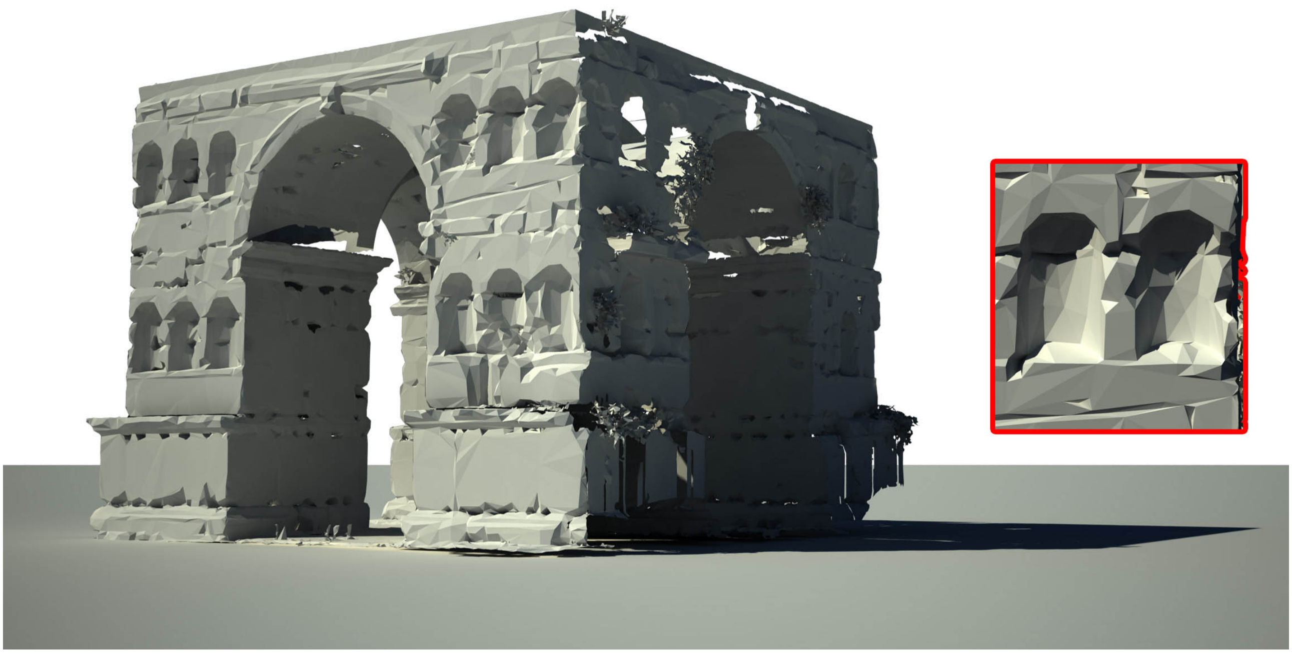

Figure 8: *Complete three-dimensional mesh model approximating a 1:200 scale of representation. Detail of the model where the level of definition of the image is defined.*

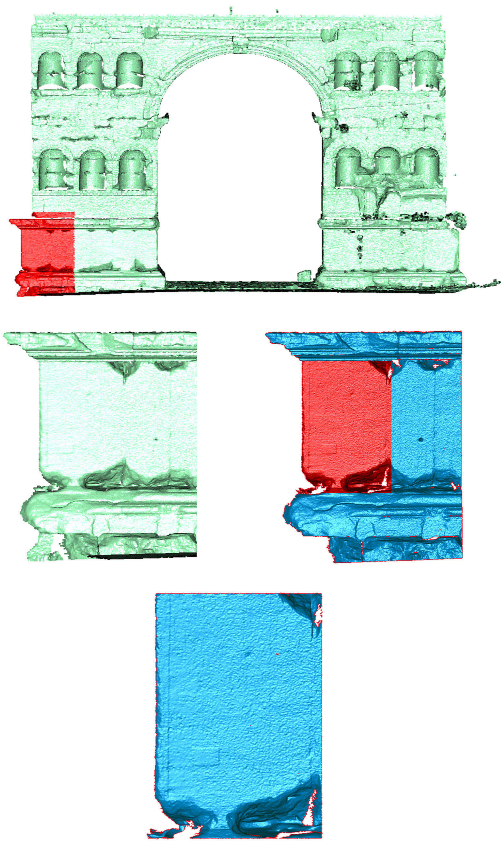

Figure 9: *Example of a detailed 3D model with a definition similar to a 1:2 scale of representation.*

reality. Of course, given the size and characteristics of the surveyed architectural object we were unable to analyse each individual part because some areas were inaccessible and some were undercuts.

To create 2D representations, i.e., plans, elevations and sections, we took several sections from the final 3D mesh model and compared them to sections obtained directly from the points cloud. This enabled us to verify how reliable the 3D model was: the difference between the latter and the point cloud was only a few millimetres and could therefore be used to create geometric 2D restitutions of the architectural object.

The mesh models provided a series of sections and cross-sections we used to create 2D images (plans, elevations and geometric sections). This was possible due to our architectural and archaeological knowledge of the arch which allowed us to identify individual parts, verify their proportions and the intrinsic rules governing them, and then draw them accurately. To characterise the surfaces we adopted a step by step approach. We first created an elevation just using lines and then developed a more detailed characterisation using data from the scan (exploiting visualisation with photographic mapping and reflectance) and analytical photographic rectification based on the coordinates of the topographic points.

At the end of the study we used the numerous high resolution photos as textures for both the 2D and 3D models, thereby providing information about the appearance and conservation of the materials. It is important to emphasise that every element of the virtual model was textured using a photograph of the real element, so that it corresponded perfectly to reality. Using the photographs we inserted the last data required by these models to become, to all intents and purposes, a valid basis for all future studies and analyses – from the study of materials to that of geometries; it also allowed us to have all useful information at our fingertips.

4. Conclusions

It is obvious that the method used to create models to define a complex 3D survey is identical to a “traditional” method in which the operator’s sensitivities and ability to make critical decisions are crucial when defining the models. The protocol focused on the dual possibility to represent both 2D and 3D models, allowing us to maintain as much data as possible in the complex 3D survey in which the dual representations compensate for reciprocal deficiencies.

The basic objective was to achieve optimal interaction between these operations in order to create a “complex” survey, exploiting each technology’s potential and scope.

Of course, the data acquisition required to understand that the object was a 360° exercise: we researched and studied archival material, historical drawings, reconstructions, etc., developed general and detailed photographic campaigns and, finally, acquired the data using high precision tools such as total stations and 3D laser scanners. Combining all the acquired data is the basis we used to develop “models” that can recreate a real object, and subsequently a complex integrated 3D survey that comes alive in an existing updated model, but in a virtual dimension. To create a complex 3D survey is like recreating an “ideal” model in a virtual

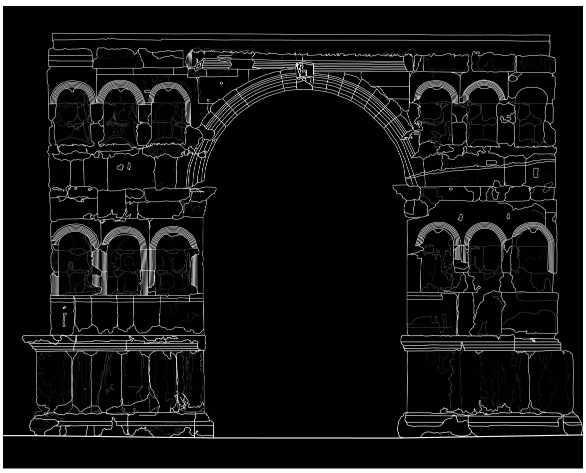

Figure 10: *Two-dimensional restitution of one of the elevations of the Janus Arch with a level of detail equal to a 1:50 scale of representation.*

environment using 2D representations (plans, elevations, sections) which are helpful to analyse the model itself as well as study its geometries; it is like recreating a digital and a physical model from the previous one. The complex 3D survey will take a virtual picture of the object on a certain date; it can then be used as a reliable reference model in the future.

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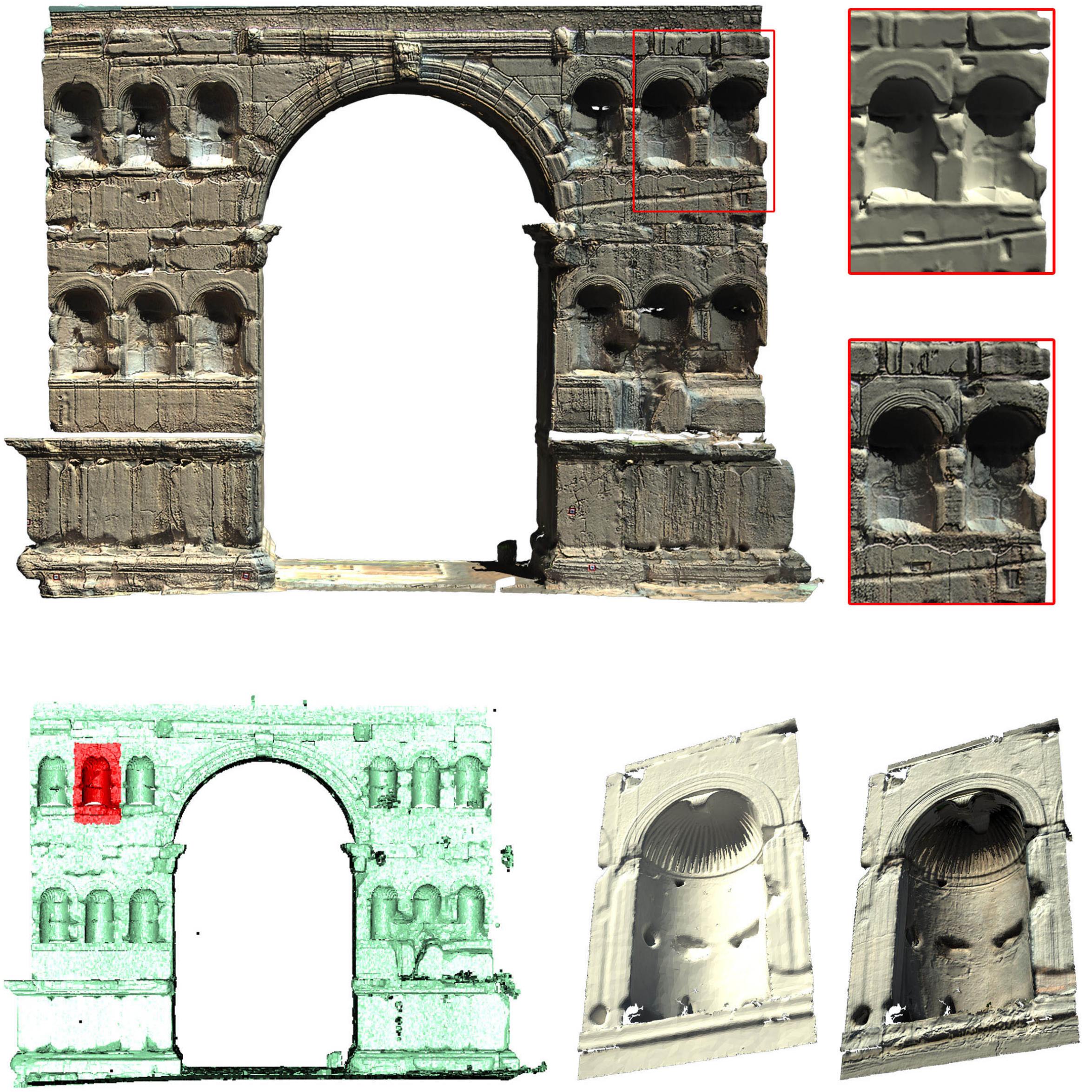

Figure 11: *Three-dimensional mesh model of one of the elevations of the Janus Arch and detail of the latter. Definition of the images similar to a 1:50 scale of representation with high definition textures.*