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Lectures and notes for a digital integrated design 2023

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This text is the result of the international collaboration activities that the CITERA Sapienza University of Rome interdepartmental research center has carried out in Italy, Indonesia, and China, thanks to the European program IURC International Urban Regional Cooperation from 2019 to 2023. The CITERA center coordinated the fourth edition of the International Summer School GIS-BIM for an integrated design promoted by the Department of Planning, Design, Technology of Architecture Sapienza University of Rome.
The Digital Twin, starting from the vast scale of GIS up to that of the architectural details of BIM, is no longer just a revolution in the built environment sector but a continuous innovation process for all technical-scientific disciplines applied to architecture. It is a path in which it is necessary to find, develop, and grow cross-cutting and multidisciplinary activities for today's students who will be the professionals of the future. The CITERA center and its community of teachers and researchers have for years been committed to sharing the results of research on innovative methodologies and organizational structures in the digital transition of architecture at a national and international level.
This text contains the lessons held by teachers from all over the world during the fourth 2023 edition of the Summer School which was held under the scientific direction of Prof. Fabrizio Cumo and the coordination of Prof. Flavio Rosa. The lessons presented in this book take the form of scientific papers, which discuss the theme of this fourth edition: the theory and practice of the Digital Twin applied to the built environment. They draw on academic research or the professional experience of individual teachers and provide in-depth analysis on the historical architectural heritage, along with integrated GIS and HBIM solutions.

GISBIM 2023

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2023 International Summer School

GIS and BIM

Department of Planning, Design, and Technology of Architecture (DPDTA)
Faculty of Architecture
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CONTENTS

Heritage Building Information Modeling of San Sebastiano Gate in Rome

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Abstract

The research focuses on the creation of a HBIM procedure of San Sebastiano Gate. An HBIM procedure is a virtual simulacrum, corresponding to what is present in reality, where all the information and data referring to San Sebastiano Gate are contained, from the digital geometric shape to the material consistency, from the state of conservation to the maintenance program, in a virtual environment. The core of the HBIM procedure is made up of federated 3D models related to each other in a data sharing environment such as the Common Data Environment (CDE).

Keywords: HBIM, Cultural Heritage, 3D modeling

1. Historical Introduction of San Sebastiano Gate

In the construction of the new walls, commissioned by Aurelian in the 3rd century AD, the extension of the road network made it necessary to build a large number of gates which, depending on the importance of the road they crossed, took on different architectural characteristics (Fig. 1).

The importance of Via Appia determines the original appearance and name of San Sebastiano Gate, which, like Flaminia way, Ostiense way and Portuense way, had two arches and an attic illuminated by arched windows with two semicircular towers on the sides. The façade is covered in travertine and the stairs, located in a central position inside the towers, allows access to the maneuvering rooms and to the crenellated terrace covering the rooms below.

The first transformations of the gate was carried out, with the rebuilding of the walls, by Honorius at the beginning of the 5th century AD and concern the renovation of the two towers which, built in a circular shape, incorporates the previous ones and are raised by two floors. The travertine façade between the towers remains unchanged, while on the internal side a double arch door is built consisting of two semicircular walls, which give rise to a security courtyard and probably connect the door to the so-called Drusus arch, one of the arches of the Antoninian aqueduct which serves the Baths of Caracalla and which at this point crosses Via Appia.

New entrances to the towers are opened in the two side walls and the internal courtyard is used not only for military functions, but also to house the offices and guards of the customs office for the control of goods.

In subsequent interventions, one of the two entrance arches is closed and, due to subsidence caused by the earthquake of 442 AD, the foundations of the gate is reinforced with the construction of two imposing quadrangular bastions that cover the first two levels of the towers. The curtain around the arch and the first floor of the bastions are covered with marble blocks which, as evidenced by the remains of the inscriptions engraved on some of them, are almost certainly removed from nearby monuments. In addition to the inscriptions, especially on the blocks on the east side, various protruding stones are visible, also present in Porta Pinciana, while from other protrusions functional to the lifting and installation of the blocks. The marble cladding of the first level is delimited by a frame while the rest of the door is made of brick.

The first floor of the attic is used as a maneuvering room for the portcullis which, by means of ropes, is lowered from above along the grooves made in the internal jambs of the entrance arch and ensured the closing of the door towards the inside.

Probably between the 5th and 6th AD, due to new structural failures, the front of the bastion of the west tower is rebuilt and the heavy masonry vaults, which divided the towers into three floors, is replaced by wooden shelves.

In the last construction phase, the towers and the attic above the entrance are raised by one level and, to cover the new rooms, a crenellated terrace is placed.

The gate, indicated in the Middle Ages as D'Accia, Datia or Dazza, in modern times takes the name of Porta San Sebastiano, in memory of the martyr buried in the catacombs with the same name.

Over the centuries, various historical events have taken place near the door or inside it.

During the pontificate of Benedict XIV, between 1749 and 1752, some restoration works are carried out which also involved the reconstruction of a large part of the battlements.

As the seat of the customs offices, the gate became the home of the custodial staff responsible for checking the goods which,

for various periods, is entrusted by the pontiffs to the noble Roman families, who are entitled to a part of the toll imposed on the goods introduced in the city and must ensure the maintenance of the same doors.

The door remained property of the Dazio until 1922 and in the years 1940-1943, despite the unfavorable opinion of the Antiquities and Fine Arts Division, it is granted as a private studio and home to the secretary of the fascist party Ettore Muti.

To adapt the rooms to the new destination, various renovation works are carried out such as the construction of wooden and masonry stairs, the reconstruction of the collapsed attics and the remaking of the brick and travertine floors with the placement of black and white figured mosaics in two rooms on the first floor.

In the years following the end of World War II, restoration and adaptation work began on the internal spaces to open the monument to the public which, since 1990, has housed the Museum of the Walls.

Currently the museum (Fig. 2), set up in the rooms of the first and second galleries and in the round rooms of the two towers, tells, with the help of models and educational panels, the history of the walls of Rome, from the Servian walls to the forts erected after the Unification, analyzing the different construction phases and the various defensive techniques used over the centuries.

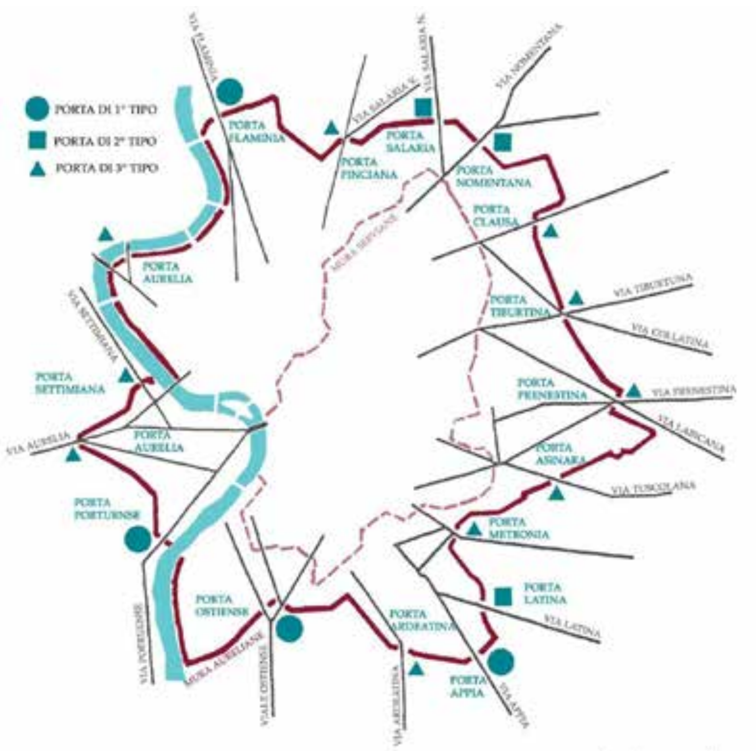

Fig. 1. Gates on the Aurelian Wall of Rome.

Fig. 2. San Sebastiano Gate today.

2. Methods-Case study

The research aims to create a Heritage Building Information Model (HBIM), containing informed data that can be used for a conservation process. The control and management of information takes place in a CDE (Common Data Environment), where there are federated models[1] related to each other, containing heterogeneous data usable in multiple application sectors. The relational system between the federated models is obtained through allowed connections or by the exchange of data in IFC format, or by the use of VPL (Visual Programming Language). The research focuses in this second direction, since the IFC format[2], to date, does not allow a perfect maintenance, and therefore transmission, of all the information referring to a single component, sometimes making the passage of data between different models complex[3].

The methodology involves the following steps:

1. Acquisition of geometric and material data;
2. Return and organization of data;
3. Realization of 3D mathematical models;
4. VPL connection;
5. Management of data and models in the Common Data Environment;
6. Extrapolation of data referring to the conservation process.

1 "Federated model" means a model made up of several models, each of which refers to a specific disciplinary area. The models are related to each other thanks to the interoperability of BIM procedures, and to the IFC interchange format, which maintains the information referring to each of the individual models produced (https://www.01building.it/bim/centralita-modello-federato - actors-process-relations / last accessed September 2023).

2 Industry Foundation Classes (IFC) data model is intended to describe the building and construction industry data (https://www.ibimi.it/ifc-cose-e-come-e-fatto/ last accessed September 2023).

3 The term "model" has multiple definitions. The "physical model", in art or design, is used to fix a design idea in the form of a physical and real three-dimensional object. The "cognitive model" connected to the meaning of "idea", which is exercised with abstraction, with a rational, intellectual and logical reflection of the cognitive experience, defines the organization of a thought or functions placed together in sequence. The "3D model", which was born with the evolution of the IT environment, defines a digitization process, which contains information and data organized in three dimensions. The last definition is the meaning of "model" used in the paper (Empler, 2002).

3. Acquision of geometric and material data

Geometric data are acquired with an integrated TLS + drone photogrammetry procedure, while the material data are collected by means of orthophotos and sampling of the materials, which allow the preparation of USM sheets (Stratigraphic Wall Unit), with indications on the type of binders and of materials that make up the masonry of the surveyed architecture.

The description of the tools used for the acquisition and the pipeline of applications for the return is a fundamental part to set up and implement a reliable and consistent HBIM procedure with the proposed methodology.

Acquisition using TLS takes place with Faro Faro Focus 3D X 130 series instrumentation, with the aid of spherical targets of 13 cm in diameter. It is a phase difference laser scanner with integrated color camera, GPS multi-sensor, compass, height sensor and dual axis compensator[4]. The result of the acquisition are .fls files, native format of the laser scanner used.

A DJI - Mavic Pro Platinum[5] is used for drone photogrammetry.

The acquisition results are .jpg[6] image files.

Outcome of the acquisition of the material data are fact sheets with photographic images and two-dimensional representations in B/W with selection of the elements involved in the acquisition. These are accompanied by samples of materials taken, subjected to subsequent laboratory analysis[7]. Acquisition using TLS takes place with focus points located about 10 meters from each other on the outside, with an anti-clockwise trend with respect to the shape of the Gate, while on the inside, following the articulation of the structure. Acquisitions have as homologous points and planes recognizable both externally and internally, and spherical targets, which facilitate the subsequent recognition stage between various acquisitions with "Scene" restitution software, native to the Faro Faro Focus 3D Laser Scanner.

Acquisition with drone provides a preliminary assessment of the "Rules of Air" in the area affected by the flight. The area has only a limitation imposed by Ciampino Airport, with free flight allowed up to a maximum altitude of 25 m AGL (above ground level).

The flight plan is set in manual mode[8], following a trend that provides for an overlap of the individual photographs

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4 The tool has the following features:
- Range Focus3D X 130: 0,6 m - 130 m indoor or outdoor with vertical incidence on reflective surface (90%);
- Measurement speed (points / sec.): 122,000 / 244,000 / 488,000 / 976,000;
- Linear distance error1: ± 2 mm;
- Optical transmitter laser: Class;
- Integrated color camera: resolution up to 70 megapixel in color with automatic brightness adjustment (HDR);
- Dual axis compensator: provides level information for each scan; accuracy 0.015 °; measurement range ± 5 °;
- Height sensor: thanks to an electronic barometer it is possible to determine the relative height with respect to a reference point for each scan;
- Compass: the electronic compass identifies the orientation of the scan. A calibration function is also available;
- Inclinometer.

5 The DJI – Mavic Platinum Pro has the following features:
- Dimensions (closed): 83 x 83 x 198 mm;
- Weight (with gimbal cap): 743g;
- Weight (without gimbal cap): 734g;
- Maximum speed (with remote control): 65 km/s in sport mode and in the absence of wind;
- Flight autonomy: 27 minutes (in the absence of wind);
- Maximum flight distance: 13 km;
- Maximum altitude 5 km;
- Internal memory: 8 GB;
- Camera sensor: 12 MP;
- Maximum video resolution: C 4K;
- Maximum remote control transmission distance: 4 km (CE compliant);
- Gimbal: mechanical with 3 axes;
- Noise: 4 dB.

6 JPG: Joint Photographic Experts Group, compression format of images captured by digital cameras.

7 Laboratory analyzes are performed by Arch. Elisabetta Giorgi, Technical Manager of the Materials Analysis Laboratory of the Department of History, Representation and Restoration of Architecture at Sapienza University of Rome.

8 The choice of manual flight is due to environmental factors that cannot be controlled in the event of a pre-set flight in automatic mode. Throughout the Rome area, seagulls see drones, of the size used, as foreign elements and invaders of the airspace. For this reason, depending on the location and height of the flight, they are more or less aggressive. It should also be borne in mind that in the entire area of the Ancient Appia Park there are both Kestrel and the Peregrine Falcon,

for at least 40%. The photos are first acquired with a nadiral view and then with a 45° view on the horizon, with a north-south, south-north, east-west and west-east trend.

Characteristics of the drone used, DJI Mavic Pro Platinum, allows to get close to 1 m from the object to be photographed, thanks to a good compensation of the turbulence generated by the rotors and reflected by the opposite walls.

Material data (Fig. 3) are collected by carrying out orthophotos with a Canon EOS 1100 Reflex digital camera fixed on a tripod, and taking representative samples for analysis of the masonry, placed in numbered transparent bags.

Fig. 3. Masonry of San Sebastiano Gate.

4. Return and organization of data

Return of data (Fig.4) purchased with TLS involves the use of "Scene" software, native to Faro Faro Focus 3D Laser Scanner, and capable of automatically recognizing spherical targets[9] and connecting individual scans together. The result obtained is a 1: 1 scale point cloud, which is integrated by the point cloud produced by the photomodeling process, to which photos acquired with the drone are subjected. Format used for the interchange is .e57, able to keep information on the points, their color and spherical panoramas generated in the acquisition phase with TLS.

Photomodeling process is performed with "Agisoft Metashape" software, which generates, in succession, point clouds, mesh surfaces and tessellated surfaces. Point cloud produced, also exported in .e57 format, must be scaled and integrated with TLS acquisition.

The 3D model of photomodeling is transferred to the CDE.

To scale the model produced by photomodeling with that of "Scene", is used an open source application such as "Cloud Compare", where are taken coordinates of the targets on the ground present both in the acquisition with TLS and with photogrammetry. These coordinates are transferred to the photos containing the targets visible in "Agisoft Metashape", so that the point cloud generated is in the same scale as that generated by "Scene".

Both export files .e57 (at this point in the same scale), are imported into Autodesk Recap, to have a single model,

birds of prey capable of capturing with their claws a drone with the size of the DJI Mavic Pro Platinum.

9 To support spherical targets it is possible to connect the homologous points of the acquisition points, placed in sequence, with the recognition of planes and points, as long as they are visible and present in sequential acquisition points.

in point cloud, perfectly integrated, where the cloud obtained with the photomodeling procedure it integrates all those parts not detected with the TLS from the ground.

The sampling of representative samples of the masonry, binders and brick or stone bricks, are subjected to laboratory analysis, in particular their characterization is performed with an optical microscopy reading.

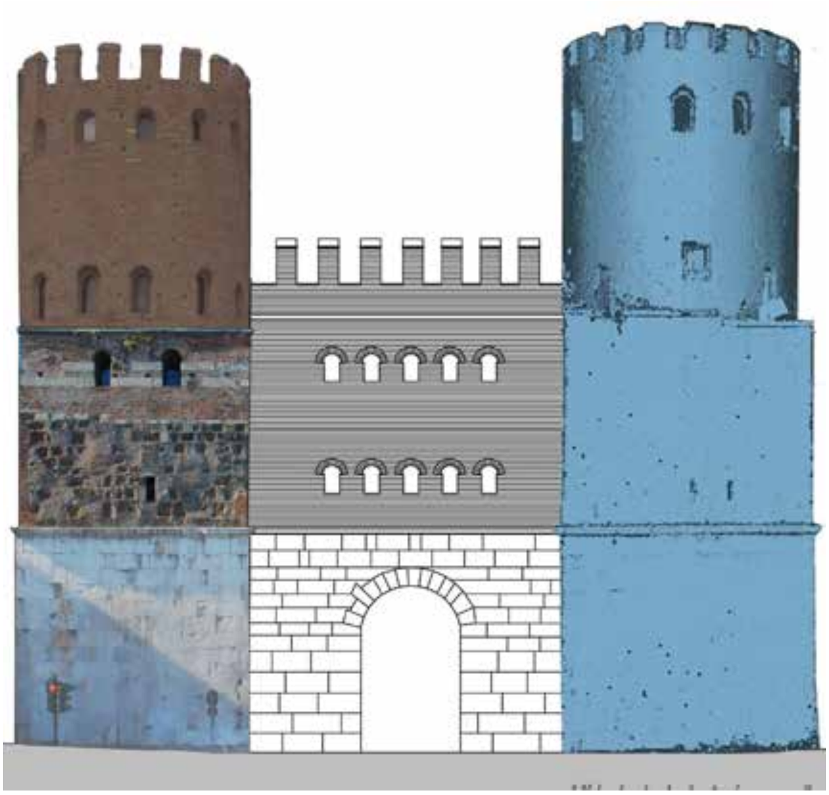

Fig. 4. Return of data: on the left 3D photogrammetry model, in the middle 3D vectorial model, on the right 3D point cloud model from TLS.

5. Realization of mathematical 3D models

Point clouds appear as a system of discontinuous points distributed in space, with x, y and z coordinates (with attributes, such as RGB values, for example).

3D modeling applications (mathematical or parametric modeling) directly acquire point clouds as objects, without having the ability to transform or modify them within their environment. The procedure is known as “scan to BIM” and is reductive with respect to the need to represent the geometric and material characteristics of architectural components belonging to historical objects with complex shapes. This fact occurs, in particular, in BIM modelers, where the informed parametric tools available tend to excessively exemplify the morphology of the acquired objects, such as, for example, a wall with an accentuated out of plumb, which is brought back to a parametric parallelepiped or the vaults inside the Gate.

This aspect is central to obtaining effective and reliable HBIM model of historic buildings and structures. An appropriate HBIM procedure must have the same characteristics as the object it denotes in a virtual way, both from the point of view of the shape and the attributes and characteristics of the various parts that compose it.

The importance of the representation of the artefact, understood as a cultural asset, is clearly evident if we consider how much the physical and material characteristics are necessary for the description of architectural objects, bearing values that must be preserved and handed down to future generations. The technical and technological peculiarities, the materials used and the layers that exist on the architectural heritage, tell the story of the monument intended as an emblem and expression of its time. Precisely for this reason, it is necessary to communicate effectively and faithfully reproduce the aspect of cultural heritage. The HBIM procedure is therefore a useful dissemination tool, an expression of the peculiar characteristics of layered architectures (Fig. 5).

Following the above indications, and operating with a mathematical 3D modeler[10], where a point cloud can be imported, there are two operating modes: segment and transform the point cloud into mesh by parts, based on the different architectural components; reconstruct with the 3D mathematical modeler the free forms present in the point cloud by parts, always referring to the different architectural components.

In both modeling modes, the "n" parts that make up each building component are created, such as, for example, the sequence: external cladding, external bearing part, filling part, internal bearing part, internal cladding.

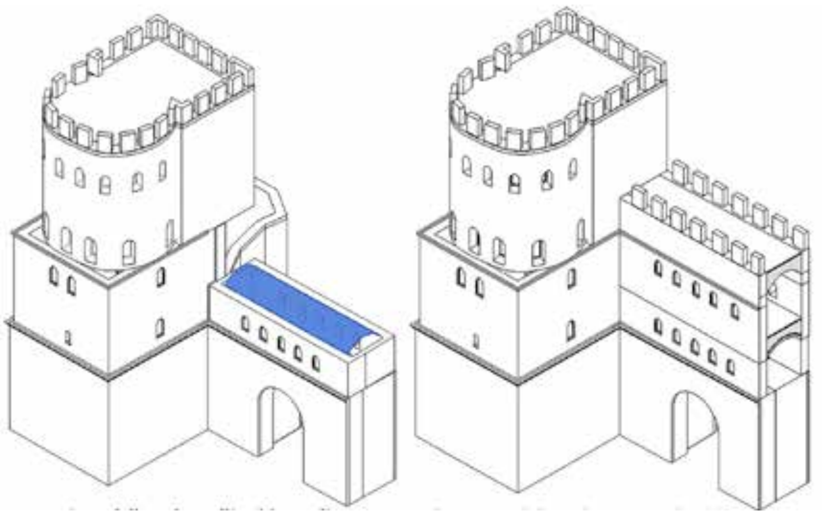

Fig. 5. Parametric 3D model of San Sebastiano Gate.

6. VPL connection between different information Return of data

Visual Programming Language[11] is a powerful means of visual connection between building parts and fact sheets containing information or data of any other nature.

A necessary and preliminary condition for any intervention on cultural heritage, performed according to information modeling procedures, is the formulation of a targeted methodological path in relation to the objective to be pursued, divided into work phases. The first action that must be performed is that relating to in-depth knowledge of the architectural object, which takes the form of the collection of information useful for recognizing the intrinsic and extrinsic characteristics of the artefact. Today's technologies provide multiple possibilities for classifying and collecting

10 In the specific case Rhinoceros release 7.0, and the Rhino.Inside.Revit plug-in (https://www.rhino3d.com/inside/revit/1.0/ last accessed September 2023).

11 A Visual Programming Language V.P.L. is a language that allows programming through the graphic manipulation of the elements and not through written syntax. A VPL allows you to program with "visual expressions" but also when you need to insert pieces of code (usually this function is reserved for mathematical formulas). The majority of VPLs are based on the idea "boxes and arrows" or the "boxes" (or rectangles, circles, etc.) are conceived as functions connected to each other by "arrows".

VPLs can be further classified, depending on how they represent functions on screen, in icon-based, form-based, or diagramming language. The visual programming environment provides everything you need to be able to "design" a program immediately; in relation to written languages the syntactic rules are practically non-existent. The advantages of visual programming are the ease of learning and the ability to view the status of the program during the debugging phases. Furthermore, parallel programming (if managed by the software) becomes almost "instinctive" and above all performed automatically. (https://it.wikipedia.org/wiki/Languaggio_di_programmazione_visuale last accessed September 2023).

information.

One of the possible ways of acquiring and transcribing information relating to real estate, proposed here, is based on the compilation of fact sheets specifically structured on spreadsheets useful for the development of qualitative and quantitative assessments, referring to the characteristics of the building. These "cards" are developed according to the specificity of the place, following assessments made by various professional figures who contribute to the achievement of in-depth knowledge of the place, following the principle of interdisciplinarity. In the case under examination, specific fact sheets were therefore prepared for the collection of information referable to the material characteristics of San Sebastiano Gate. The intent is to find a way of correlation between the "cards", previously described, and the three-dimensional object by generating textured meshes.

It should certainly be noted that among the many IT tools that can be used, in the field of cultural heritage management, there is still no fully consolidated effective exchange format. For this reason, it is desirable to hypothesize the use of additional components that make it possible to overcome this problem and ensure effective solutions by performing the arduous task of interchanging between different types of IT structures. Undoubtedly, the Visual Programming Language is one of the components that can be counted, which is able to direct the actions of the software through the graphic manipulation of the elements and not through written syntax (Fig. 06). In particular, using some specific software it is possible to create an effective connection between the fact sheet, previously formulated and compiled in relation to the information acquired with the evaluation of the characters of the Gate's walls, and the textured mesh model. The structure of the VPL code, "built" for the specific case study, consists of two main subgroups: the first dedicated to the transfer of the contents of the spreadsheets within the VPL language and the second intended for the association of each parameter to the individual portions of the artefact, previously identified and returned as independent digitized objects.

The first phase is structured starting from an operation that provides for the simplification of the fact sheet according to formats compatible with the VPL language. This first step, apparently not very relevant, is on the other hand a necessary condition for understanding the wall data of the visual programming language. The second subgroup, on the other hand, is functional to the effective association of any information with the selected mesh object.

Through the VPL connection of the Rhino.Inside.Revit plug-in, it is possible to report directly on the architectural 3D model, present in the CDE, the mapping of degradation.

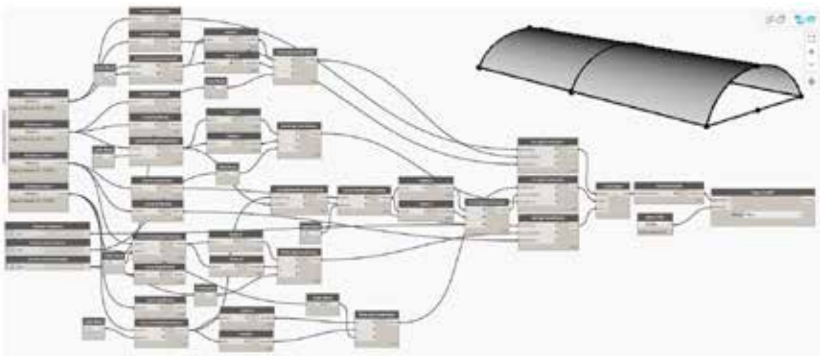

Fig. 6. VPL procedure for the reconstruction of a vault.

7. Management of data and models in a Common Data Environment

A CDE[12] is the central part of a HBIM procedure, it is the area that contains digital information and that centralizes the storage and access to project data, made up of federated models.

12 The concept of the ACDat Data Sharing Environment has been introduced in Italy in recent years by the UNI 11337 standard and is defined as an "Environment for the organized collection and sharing of data relating to models and digital documents, referring to a single work and to a single complex of works". The legislation makes a clear reference to the Anglo-Saxon term Common Data Environment (CDE), introduced long ago by BS 1192: 2007, and over the years it has represented a tool that has facilitated the exchange of information flow between counterparties (https: // www.ingenio-web.it/29319-ambienti-di-condivisione-dati-acdat-focus-sulla-titolarita-di-tali-ambienti last accessed September 2023).

The data stored in a CDE originally consisted of BIM data and information. A CDE includes the Project Information Model (PIM) and the Asset Information Modeling (AIM), which concern graphical, non-graphical data and documents of any other nature associated with the HBIM procedure, such as: documents such as project contracts, estimates, reports, material specifications and other information relevant to the processes of design and construction, maintenance, conservation and enhancement.

A CDE is an inclusive repository of data generated by all those figures of experts who are able to iwork on the digital model in any capacity. Interested parties in the HBIM procedure can access the CDE anytime, anywhere using a computer, mobile phone, tablet or machines in the field.

Data contained in a CDE are manifold, as are their formats, the relationships are established with interchange formats, such as the IFC, or relationships between parts and complex components using the VPL described in the previous paragraph. In this way it is also possible to make the federated models generated for the definition of HBIM models communicate and relate to each other.

8. Extrapolation of data referring to the conservation process

The conservation process of San Sebastiano Gate is made possible thanks to the data contained in the federated model, which contains information on the state of decay and on the interventions to be carried out to carry out an organic scheduled maintenance program (Fig. 7). CDE of the HBIM model contains data on the nature of the binders present, and therefore to be reproduced, as well as on the types of masonry present. The federated model contains the 3D mapping of the degradation, quantity and quality of the work to be performed, in addition to the economic values and the time schedule to follow to conduct the intervention.

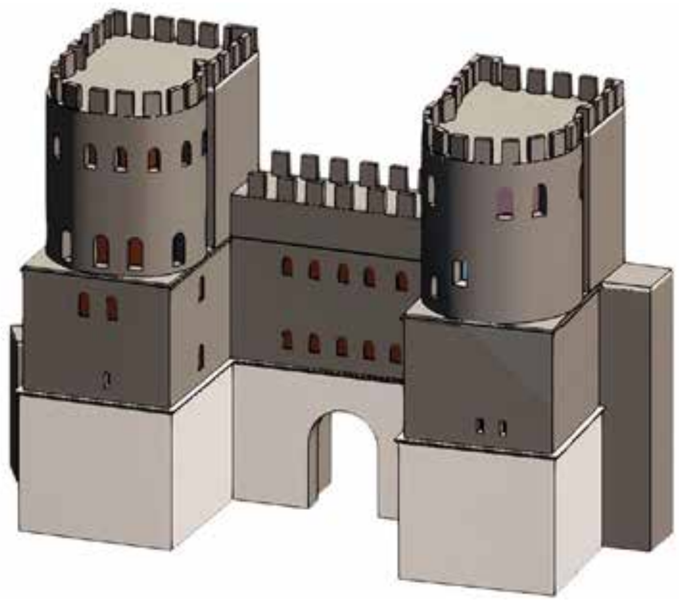

Fig. 7. Federated model of San Sebastiano Gate.

9. Conclusion

An HBIM procedure can be seen as an evolution of information modeling procedures known as BIM. If they are above all an operational and managerial character of the project and construction site phase, HBIM represents a 360° transition from the physical object to its digital replica. It is a tool for analyzing and modeling the interactions between people and the built environment. Its application to the field of built heritage not only indicates the possibility of interactions in real time, but also the possibility of managing a CDE composed of federated models organized, managed and interrogated in such a way as to have multiple answers, concerning both the construction sector but also that of communication and enhancement of the same structures. The application case on San Sebastiano Gate, thanks to a Scientific Collaboration Agreement between the Department of History, Representaion and Restoration of Architecture and the Capitoline Superintendency, also highlights how research must also be applied, going more and more in the direction of Third Mission.

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