

Building information modelling and digital fabrication for the valorization of archival heritage

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ABSTRACT

Archives of the 20th century are today the focus of many scholars in the disciplines of conservation, valorization and communication. The enhancement of archival heritage could benefit from the methodologies, techniques and tools offered by the current digital revolution. This is the case of the work shown in this proposal. A parametric modelling experience was developed for the project of "Due case a Capri" by architect Aldo Morbelli (1942) starting from archival documentation and from a previous graphic, manual and critical reading of the project. The aim of this research is to build a methodology able to reproduce 3D objects through building information modelling technology, integrating geometry with semantic information up to the realization of a scale models, through the application of different prototyping techniques.

Section: RESEARCH PAPER

Keywords: Architectural Archives; archives; BIM modelling; digital fabrication; rapid prototyping

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1. INTRODUCTION

Through this contribution, the author intends to deepen some aspects and themes already addressed previously through two different papers both focused on the project of "Due Case a Capri" by Aldo Morbelli (1942): the first one focused on the role of redesign and the use of traditional and manual techniques (Figure 1) [1] for the understanding of the project, the second on the realization of a real model through the application of Digital Fabrication techniques from a digital reconstructive model using the BIM Revit® software [2].

Archives of 20th century architecture represent today an important source for scholars to gain a profound understanding of architectural designs. The interpretation, use, and sharing of archive materials are activities aimed at deepening the knowledge of contemporary masters and the different architectural movements [3], [4].

Building Information Modelling (BIM) is applied here as a tool to rediscover, analyse, interpret and highlight architectural design, thus contributing to the recognition of architectural archives as Cultural Heritage.

The author, after a careful analysis of the project drawings of the villas, obtained the 3D model working directly with Revit® on the archive drawings, and then focused the final attention on

the different methods of rapid prototyping and on the realization of a real scale model.

The realization of 3D digital models and real models of architectures that have never been built represents an important contribution to the study and knowledge of archival drawings and morphological aspects. If the virtual space facilitates and increases our perceptual knowledge of architecture, allowing a different way of understanding space, the physical model produced by a 3D printer allows easier reading of architectural morphology [5].

2. DRAWING AND ARCHITECTURAL LANGUAGE OF ALDO MORBELLI AND THE PROJECT FOR THE "DUE CASE A CAPRI"

Aldo Morbelli (1903-1963) is an Italian architect, born in Orsara Bormida in Piedmont. After graduating from the Faculty of Architecture in Rome, he founded his professional studio in Turin in the 1930s. During his professional activity, Aldo Morbelli produced several architectural projects concerning single-family houses, social housing for the INA-CASA Plan, entertainment buildings, company representative offices, and post-war reconstruction works. In addition to these projects, he has also worked on interior design and furniture design studies.



Figure 1. Interpretative drawings for the project of the "Due case a Capri" (Drawings by Giulia Bertola)

Aldo Morbelli's archive is kept in the Biblioteca di Architettura "Roberto Gabetti" of Politecnico di Torino and contains several documents relating to his projects, both completed and unfinished.

Despite the fact that in the past many of his projects have obtained recognition in internationally renowned magazines and the critics have dedicated a monographic issue in *L' Architettura Italiana* to his single-family houses, to date, the figure of Aldo Morbelli is still little studied [6].

He affirms himself through a poetics that tends to a process of formal simplification, to a careful research of balance between project and insertion in the context (Figure 2). This is particularly evident in the project of "Due case a Capri".

The buildings, never realized and defined by Morbelli Large house (located lower down) and Little house (higher up), are thought to be situated on a land among the olive groves at the foot of Mount Tuoro, in the region "La Cercola".

The two buildings are facing west because of the steep slope of the land. He breaks the compactness of the volumes through the reference to the local architecture, solved through the insertion of segmental arches, the choice of colours and materials for walls, and coatings such as white.

Also, in the interior spaces there is a clear intention to give the rooms a plastic sense: the walls and the distributive elements, such as the "S" staircase of the Large house adapt to the plan (Figure 3).

The Little house is on three levels, basement floor for servants and storage, ground floor with living room and kitchen, which is accessed through a sloping wall with arched entrance, and first floor with two bedrooms.

The Large house, instead, is only on two levels, the lower level is for the living area, with the living and dining area at double height that occupies all the sea view front and that of the services develops towards the mountain, while the highest level is for the sleeping area, with four bedrooms.



Figure 2. A. Morbelli, real-life drawings of Mediterranean architecture (Archives of the Library of Architecture "Roberto Gabetti", Polytechnic of Turin. In the following Archivi BCA. Fondo Aldo Morbelli).

Looking at the drawings, it can be seen that the architect wanted to experiment with the insertion of different types of roofing: horizontal flat and sloping flat for the Little house, barrel and net vaulted for the Large house.

3. THE BIM MODEL GENERATED BY ARCHIVE DRAWINGS

This contribution aims to show a methodology for the management, preservation, and communication of archival material by integrating data with 3D modelling techniques.

This type of documentation, if inserted within a virtual database, can become an active component of the Archive itself, contributing to the general knowledge of lost or non-existent architectural artefacts.

This theme opens a series of reflections regarding the philological interpretation of the unrepresented parts of an architectural project and the translation of the drawings of an unrealized architecture into a three-dimensional model.

Digital modelling with archival sources involves investigative work starting with the hypotheses of reconstruction of the sketches, checking the consistency of the scale drawings, and proposals for integrating missing data.

The source of research, in this case, is the analogical documentary heritage. These consist of graphic, iconographic, and textual sources. For each reconstructive model, it is necessary to identify the phase of the project to which it refers according to the cognitive values that one wishes to emphasize through the research work [7].



Figure 3. A. Morbelli, study sketches for the two houses in Capri (Archivi BCA. Fondo Aldo Morbelli).

Archives could therefore become a place where to build, communicate and share knowledge within a complex system of relationships made up of different actors (institutions, curators, scholars, public), types of heritage (material, immaterial, real three-dimensional artefacts), and digital technologies (interaction, immersion, virtual and augmented reality) [8].

The construction of the model makes it possible to produce a variety of elaborates including real three-dimensional models to be made available to different users.

As underlined by the London Charter (2008) [9], it is the responsibility of the scientific community to ensure the sustainability of digital heritage, for example by promoting the use of open formats, favouring as much as possible the access to data to the community of users, experts or not.

These operations are well suited to BIM tools. They provide a good level of interactivity and consider the stages in the temporal evolution of the project.

A BIM information system can represent the "sustainable container" and the appropriate means for the transmission of knowledge (for example through advanced Building Information Exchange systems).

In the HBIM environment, as in this case study, the operator must be able to manage complex and heterogeneous survey data (photographs, documents, sketches), master geometrical constructions, know construction techniques.

The potential of Historical Building Information Modeling systems, despite the methodological and operational difficulties, allows building a database capable of managing large amounts of multidisciplinary data [10], [11], [12].

BIM also offers the possibility of managing the life cycle of architecture, from the first hypotheses to the design and construction phases in a single model, and can facilitate the creation of models from the archival heritage.

Some significant examples of the use of BIM technology as a tool for interoperability and advanced information management technology have emerged in some studies by Saygi and Remondino (2013) [13] which emphasize the semantic enrichment of three-dimensional digital models through the integration of heterogeneous data sets and in the Arches (2018) [14] and Inception (2016) [15] projects; the latter aim to make

available interoperable information through multiple services such as websites, digital maps, applications, and 3D models. While the first one is focused on the creation of an international community of computer scientists and heritage professionals to share experiences, knowledge, and skills for the management of digital inventories, the second one is a project that aims at the development of advanced 3D modelling for the access and understanding of European cultural heritage. In particular, the HBIM modelling process starts with the documentation of user needs, the identification of Cultural Heritage buildings semantic ontology, and data structure for information catalogue integrated with the 3D geometric model.

A last interesting study is Cult Project (2018) [16], a project in which a software toolkit was developed to store data from architectural heritage research projects and share them with websites, tourism applications, and BIM and GIS interfaces.

For the "Due case a Capri", it was decided to use the Building Information Modelling methodology and build a three-dimensional model using Revit 2021®. After scanning and digitizing the original drawings of the project, the documents were inserted into the Revit 2021® software.

To optimize the modelling process, the files in .jpg format were not imported into the model but only linked to it. Initially, the plans were linked at 1:200 and 1:500 scale. Thanks to these, it was possible to correctly set the geolocation data, create a topographic surface and import contour data.

After having identified the correct positioning of the buildings, we proceeded with the insertion of technical drawings at scale 1:100 containing plans, elevations and sections of each villas and territorial sections.

Each drawing has been scaled with reference to the dimensions reported on them and used as a base on which to set the model. Following the scaling of the images, the most significant work plans have been identified and a grid has been built for the alignment of plans, elevations and sections (Figure 4).

The axes of the grid, besides being a useful trace for the construction of all the elements that will compose the model, also represent the tool to facilitate the reading and verification of the original drawings.

This phase of work, to be done correctly, requires prior knowledge of the main volumes that make up the buildings. Once the volumes had been identified, we proceeded with the identification of the types of walls and floors, attributing to each one a specific thickness: perimeter walls (60 cm), partition walls (10 cm, 20 cm), and floors (40 cm) (Figure 5).

Where it was not viable to refer to a System family, it was decided to use the In-place masses to create the roofs and curved elements present in some portions of the external walls and on the railing of the internal staircase of the Casa Grande.

All the masses have been transformed into surfaces. During the modelling of these elements, some problems related to the rigidity of the BIM method in the modelling of unconventional shapes emerged.

The In-place masses were created using the Swept Blend command, which, however, did not make it possible to faithfully reproduce some of the most characteristic architectural elements of the project and typical of Aldo Morbelli's poetic.

During the final phase of elaboration of the BIM model, it was chosen to refer to the original plastic models not preserved but documented photographically. In order to maintain formal coherence, it was decided to create monochrome grayscale rendered views (Figure 6).

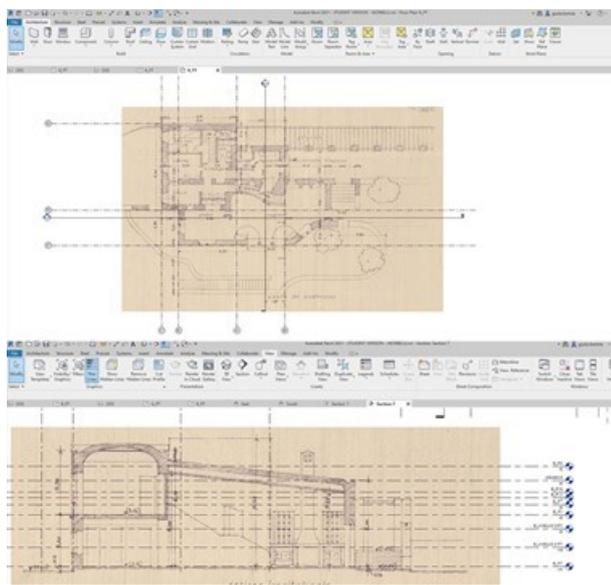


Figure 4. Inserting archive images (Archivi BCA. Fondo Aldo Morbelli) on Revit 2021®.

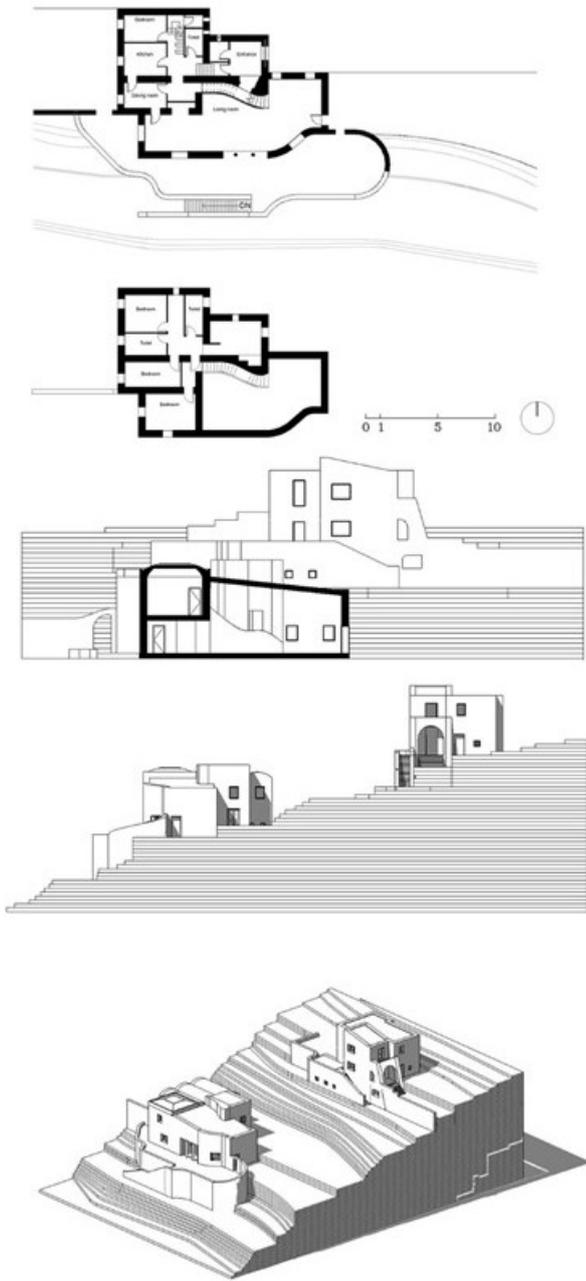


Figure 5. Plans, section and elevation of "Casa Grande" created through Revit 2021®.

Also, in the elaboration of plans and sections, it has been chosen to reach a level of detail that can be hypothesized at a scale of 1:200 in order to avoid distorting the original project by providing incorrect interpretations and additional information.

Moreover, since it is a preliminary project, without detailed information about structures, stratigraphies, and construction details, it was decided to use generic model families, avoiding the customization of the library of parametric objects.

In the future, this work aims to use a philological approach based on the classification of archive documents. The different sources (sketches, final and executive drawings, documents, articles, photographs, and physical models) can be linked to the digital model and referred to at different levels of analysis.

Each level corresponds to a quantity of information that, when added to the previous level, increases the level of reliability of the reconstructive model with the original drawings.

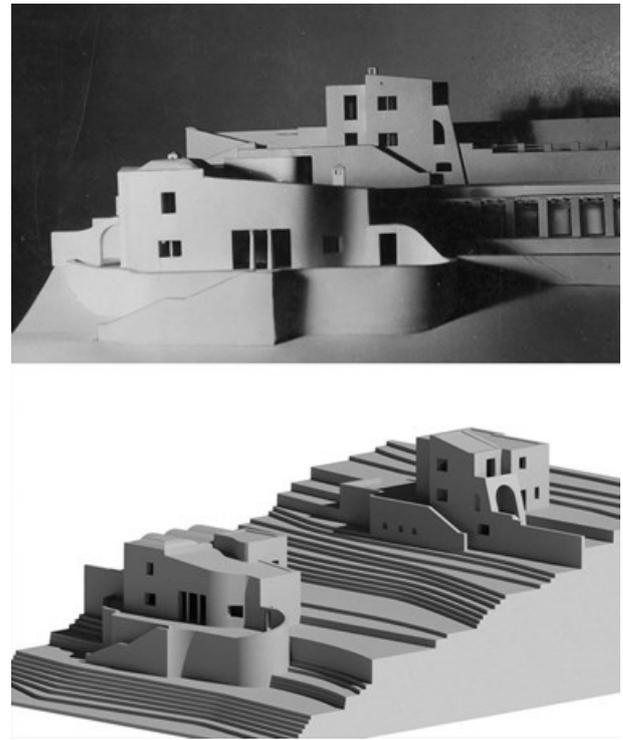


Figure 6. A.Morbelli, photograph of the original model (Archivi BCA. Fondo Aldo Morbelli) and view rendered through Revit 2021®.

The BIM methodology provides a gradual definition of the 3D model, with geometric accuracy and data content. In some countries the levels of detail coincide with the levels of the 3D model, Level of Detail (LOD), and in others with the levels of information, Level of Information (LOI), transmitted where graphic data are missing, thus suggesting a different relationship between model and real object [17].

These levels can be declined within the framework of Historic-BIM (H-BIM), even though partial documentary sources, such as those in the case of unbuilt architecture. The concept of the LOD development level applied to BIM management is based on a linear process that progressively enriches both the model and the information through the different phases. These phases correspond to: LOD 100 represents an a-dimensional conceptual model, LOD 300 a three-dimensional model in the executive design phase, LOD 350-400 represents the implemented model for the construction phase, LOD 500 the as-built update after the construction phase. In this case, the LOD will correspond to the design level at which the architectural design was interrupted [18], [19], [20].

4. DIGITAL FABRICATION AND RAPID PROTOTYPING TECHNOLOGIES

This paper aims to focus on the effectiveness of Digital Fabrication processes and Rapid Prototyping techniques for the valorization of the archival heritage. In this context, Digital Fabrication is considered a working method to support the entire design process for the study of form and the built environment.

Digital Fabrication is a process by which solid objects can be created from digital drawings.

A process capable of exploiting different manufacturing techniques. The choice of a technique is usually made following

some considerations made on the speed of processing, the cost, the material, and the final aesthetic performance [21].

Here below, we compare the two main categories of prototyping techniques: subtractive and additive methods of manufacturing.

The first are based on the idea of reproducing an object by sculpting a block, removing material over a predetermined path. This operation is feasible through two types of machines: the *Computer Numerical Controlled (CNC) machine* and *Laser Beam machine*.

Whereas the *CNC machine* is a milling tool, the *Laser Beam machine* involves a thermal separation process. The laser beam hits the surface of the material and heats it up to the point where it is melted or completely vaporized. Once the laser beam has completely penetrated the material at a certain point, the cutting process begins. The laser system follows the selected geometry and during this process the material is separated.

The additive process, usually called 3D printing, is instead a process by which solid shapes (usually of small size) are constructed by building one layer at time.

Nowadays there are several additive manufacturing processes that differ from each other depending on the different materials that can be used and how they are deposited to create the various objects. All 3D printing processes involve the simultaneous collaboration of software, hardware, and materials and have the great advantage, compared to subtractive processes, of being independent from the geometric complexity of the digital model. In addition to the Fused Deposition Modeling (FDM) printing technique, explored in the next paragraph there are other three main types of 3D printing [22].

Two prototyping techniques were used for this work: FDM for buildings and Laser Beam Machining (LBM) for the ground.

4.1. Fused Deposition Modelling

The FDM it is the most common 3D printing technology. This method uses a filament (a string of solid material), which, under the thrust of a heated nozzle, melts. The printer continuously moves this nozzle around, laying down the melted material at a precise location, where it instantly cools down and solidifies. This builds up the model layer by layer. During the construction of these solid shapes it is often necessary to use vertical supports to sustain overhanging parts.

Vertical supports can be made with water-soluble filaments that when immersed in water can be removed easily without leaving hard-to-remove residue.

The filament used in the FDM process usually requires a specific diameter, strength, and other properties.

During the extrusion of a polymer, the diameter of the filament must be uniform. To achieve this, the machine must have adjustable screw speed, pressure, and temperature. All these parameters are examined and selected until an optimal filament diameter is reached. For a smooth filament, a different calibration nozzle was used. For low-temperature materials (polylactic acid PLA, polyethylene PE) the calibration nozzle is made of copper and the thermal seal is made of

polytetrafluoroethylene. For high-temperature materials (Acrylonitrile butadiene styrene ABS, polyamide PA) the calibration nozzle is made of aluminium [23]. Following the printing process, to avoid seeing the layers it is often necessary to sand and polish the surfaces.

For this case study, the buildings were made in PLA and printed using the Delta Wasp 2040 Industrial line 4.0® printer whose characteristics are shown in Table 1 [24].

Once the Standard Triangle Language (STL) format was obtained, a test was made to verify the file through the software Cura®, an open-source slicing application for 3D printers through which an analysis of the model was carried out: thickness, stability, positioning, and orientation of the model on the surface. The STL file was also automatically divided by the software into sections (slices). The software also automatically generates the support structures.

The plastic filament is conducted in a reel, pushed, and melted through the extrusion nozzle. When the loose filament comes into contact with the construction plane it hardens and the rest of the material is support structure needed gradually released [25].

4.2. Laser Beam Machine

For the realization of the ground we chose instead to use another Rapid Prototyping tool: LBM.

The soil was made of 2 mm thick cardboard using the Totrec Speedy 400® printer.

Totrec Speedy 400 is a type of CNC machine. The user can process an object through a design software, send it to the laser cutting machine and have it cut it automatically. Once the design is sent to the machine, the device uses a laser beam to cut or engrave the material on the cutting plane. This type of processing allows wide versatility in materials, no need for subsequent machining and high precision.

From the 2D file generated by Revit 2021® you can proceed with the print layout operations, defining the cutting power values using the Job Control® software.

5. FROM BIM MODEL TO PROTOTYPE

Some of the studies regarding the relationship between BIM objects and Digital Fabrication processes reflect on how such objects can be incorporated with the semantics of fabrication and how they can then be used to support the workflow between designers and fabricators. A reflection that is applied in particular to CNC Fabrication and proposes specific process maps for the conventional workflow between design and fabrication disciplines from the domain of custom cabinetry [26].

BIM then, in support of digital workflow design for all building disciplines, including the use of structural information models for digital fabrication of steel structures[27].

Another area of reference is the construction industry explored in-depth in Sakin and Kiroglu studies (2017) regarding new 3D printing technologies for sustainable buildings and pointing to *Contour Crafting* as a promising technique that may be

Table 1. General characteristics of Delta Wasp 2040 Industrial line 4.0®.

System	Printer Model	Max. Build Size	Accuracy	Materials	Advantages	Disadvantages
Fused Deposition Modelling	Delta Wasp 2040 Industrial line 4.0®	200 × 200 × 40 mm ³	0.1-0.2 mm	PLA (Polylactic acid)	Good Accuracy. Functional materials Medium range of materials. Office friendly.	Support structure needed

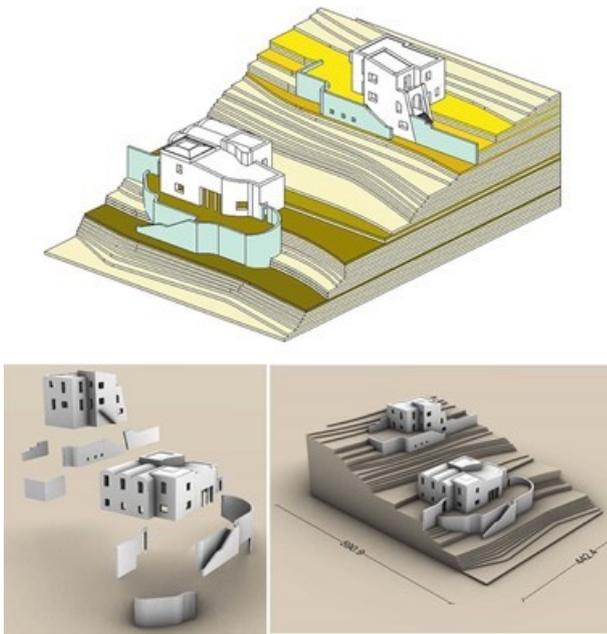


Figure 7. Organization of the model for the printing process through Revit 2021® and Rhinoceros®.

able to revolutionize the construction industry in the near future [28].

For the current case study following the choice of prototyping techniques, attention was paid to the preparation of files for printing. For the construction of the terrain, we started with the 2D file generated by Revit 2021® and proceeded with the print layout operations, defining the cutting power values with the Job Control® software (Figure 7).

To proceed instead with the 3D printing, since an STL Exporter for Revit 2021® is not yet available, the file was exported in 1:100 scale in FBX format, imported in Rhinoceros® and then exported in STL. During the import phase in Rhinoceros®, the 3D model was scaled to 1:200 and the unit of measurement was changed to millimeters. For dimensional issues related to the printing dimensions of the machine, the models were divided into parts: building blocks and outer walls.

In addition, for the realization of the volumes, neutral colours were deliberately chosen so as to focus the viewer's attention on the three-dimensional geometries and the composition of the volumes.

The level of complexity of the model determines the number of triangles needed and their size.

In turn, the number of triangles determines the size of the file. As happened in this case, it may happen that during the conversion of the Revit file to STL, critical issues emerge, and the exported file may contain some errors. These errors can be of various types: holes or blanks, inverted or intersected triangles. (Figure 8)

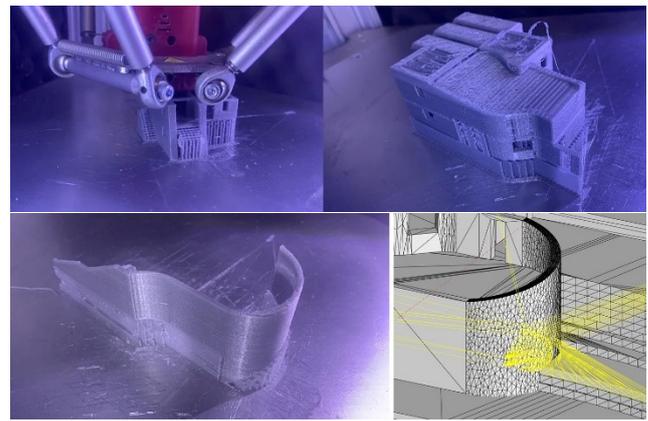


Figure 8. The external wall of the "Casa Grande", imperfections during the printing phase due to errors on the model after the export from Revit®.

During the printing phases, the goal is to obtain objects characterised by continuous and well-finished surfaces.

For additive manufacturing, the surfaces of the 3D model are converted into mesh, a mesh composed of triangular faces and vertices connected to each other. During conversion, you may get a model with mismatched edges, holes, and triangles that intersect each other in incorrect positions.

In particular, the mesh for 3D printing must have the following characteristics: the surfaces must be closed and all triangles must connect with other triangles along the edges without intersecting and must be correctly oriented.

In particular, Netfabb® software was used for file repair operations. Netfabb® is a software for editing STL files and offers a rich set of tools that optimizes workflows and minimizes building errors. The procedure used for the small house was as follows: open STL file on Netfabb® and verify the quality of the 3D model by checking the number of triangles that make up the model (13316). Subsequently the software indicates that the file has errors, then proceed to click on *Automatic Part Repair* to repair the part automatically. This operation will show us what's wrong with this model. This was followed up by checking for incorrectly oriented triangles and then clicking on the commands *Prepare* and *Repair Part*. Following these operations in the table on the right of the screen appear the new values for *Edges* (3588), *Triangles* (2392), *Inverse orientation* (615), *Holes* (0), *Border edges* (0). At this point we can start the repair process of the file with the command *Run Repair Script* and *Extended Repair*. From this procedure it has obtained a new model with new values of *Inverse orientation* (0), *Holes* (0), *Border edges* (0), *Edges* (4968) and *Triangles* (3312). (Figure 9) At this point was possible to export the STL file, open it with Cura® and print it. (Figure 10)

The final result has numerous imperfections. The surfaces, despite the high level of accuracy (Table 2), are not smooth and the material has not been deposited evenly. This is due to the poor quality of the mesh. These problems can hardly be completely solved with mesh repair software.

Table 2. Values and print settings used on the slicer Cura® for the "Due Case a Capri" 3D printing project.

Quality	Infill	Support	Time	Material	Quantity
Layer height	Density Pattern grid	Enable	12 h	PLA (Polylactic acid) Gray	40 g
0.1 mm	20 %				

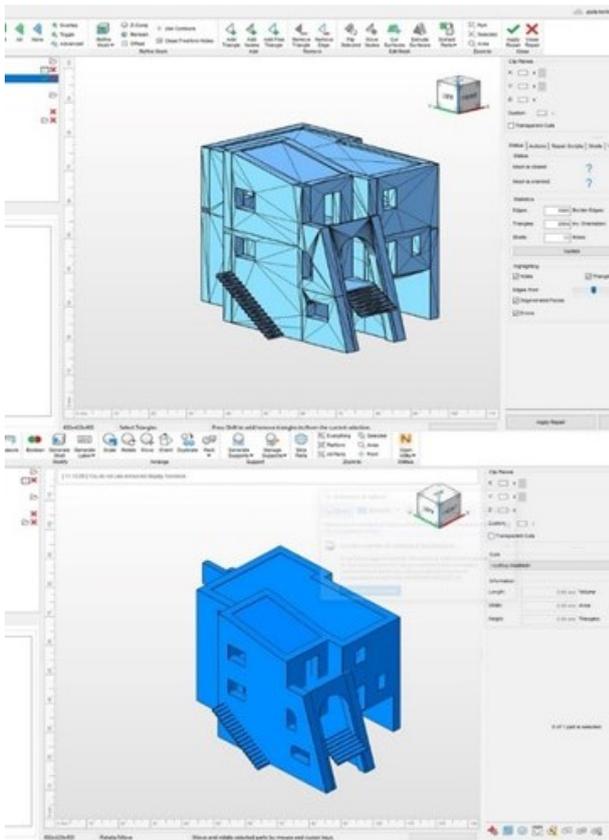


Figure 9. The STL file before Repair operation in Netfabb® and the STL file after Repair Operation.

To obtain higher quality printable 3D files that can still be computed in Revit®, an alternative method could be used using Rhino.Inside.®Revit. This would involve modelling the object in Rhinoceros® (one of the most suitable software for transferring 3D geometries to rapid prototyping tools) [29], importing it into the Revit® file, and assigning Families and Types to the surfaces of the mesh.

6. CONCLUSION

In the scenario of the digitization of archives, the 3D modelling phase allows extending the consultation of archival material, placing drawings and photographs alongside three-dimensional models that can be explored through virtual reality and augmented reality experiences [30], with the application of different digital interfaces, machine learning techniques and computer supports. These technologies allow archives to catalogue and publicly show their content at any time through interactive support, allowing curators and scholars to greatly enrich the narrative experience. Archives can place visitors virtually within the experience, leaving them free to explore the content actively, helping to build a deeper connection between visitors and archival [31].

The prototyping phase could, in addition to becoming an ideal context to experiment with the flexibility of the different printing techniques, give users the possibility, during the visit to the archive, to consult not only the original drawings but also plastic models (possibly decomposable) that allow a better understanding of the three-dimensionality of the artefact. This could be particularly useful and significant in the case of unrealized architectures, such as those treated in this case study,

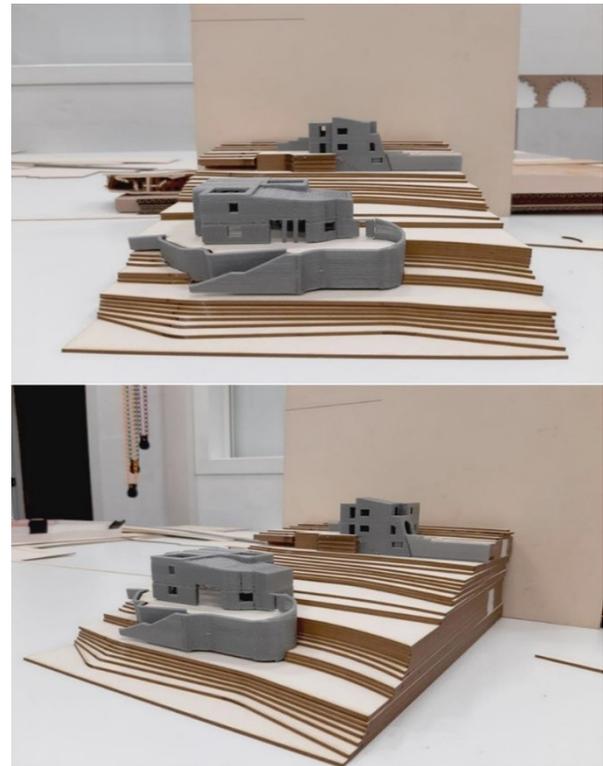


Figure 10. 3D Printing process and the final real model.

and thus become the first and only physical representation of the artefact.

The aim is to demonstrate that the conjectural reconstruction through digital models is an act of clarification of some aspects of architecture, often only left to the written word; through the construction of new representations the words take shape through a new figurative corpus; the digital model is not only the virtual image of the building but it becomes a possible image, becoming its only existential reality [32].

Given the problems that emerged during the preparation of the file for printing and the medium to low quality of the final printed model, the application of BIM technology to achieve high-quality 3D printing operations still needs to be further investigated.

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