

## SCAN TO BIM PROCESSES: HERITAGE ACCURACY VERSUS BIM SEMANTIC

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### ABSTRACT:

The contemporary process that leads digital surveying of Cultural Heritage to the creation of informed models in a BIM environment follows paths that are now codified for most; however, processes to improve the workflows both in terms of accuracy of results and speed of process still arise. The main cause lies in the lack of interoperability between modelling software NURBS oriented if related to parametric BIM-oriented software. The possibilities of interfacing one with the other have grown exponentially. On one side BIM oriented software look for more accuracy in defining shape objects even if complex or irregular; on the other NURBS modellers look for solving lack of information, necessary for any informed model. Our research question grows in this area and concerns three ways of reconstructing a Neo-Gothic tower to be imported into a parametric modeler for its BIM definition from an accurate point cloud. Workflows are compared to define accuracy, information addable, speed of creation.

### 1. INTRODUCTION

#### 1.1 State of the art

Many recent studies interfaces with the issue of complex geometric volumes; they need to be developed with the qualities of informed models within BIM environment. Looking at the production of the last five years, there is a consistent progress toward the perfect reproduction of the Heritage building within the parametric model (Spallone, 2019). The main reason for this research is the desire to bring design renovation (Adami et al, 2021) environment (Chiabrando et al., 2017), closer to BIM environment by sharing within this area the same advantages that BIM has over the new construction field (Ori, 2021). As BIM environment software becomes more and more specialized by introducing new tools for modelling complex shapes, in parallel, various techniques have been experimented to support the workflow with cad software or Nurbs software. In the first group the possibility to export from Cad software into format compatible with BIM software (ACIS, DXF), or in case of complex point clouds the techniques of slicing them to recreate non-standard objects to be exported have been investigated. All these techniques are weak from the point of view of the information apparatus if non-existent and refer only to the geometry (Bianchini et al, 2018) of objects and attempts to import them inside some BIM parametric family to associate manually their information content (Rocha et al., 2020). In the second group a deeper investigation that goes from mesh modelling to NURBS modelling and involves several new tools and plug in to bridge complex modelling and information enrichment into BIM environments (Capone, 2019).

#### 1.2 General overview

The process leading from surveying with digital techniques in the heritage field to the creation of informed models in the BIM environment offers continuously improved workflows in terms of accuracy of results and speed of the process. However, the speed of data acquisition offered by laser scanner technology in Cultural Heritage is much faster than post processing in the BIM domain and in the meanwhile the loss of data accuracy in a BIM model is a sensible part of the more general modelling issue. The accurate analyses that can be performed to preserve the knowledge of the building go hand in

hand with the accuracy of the model; faithful rendering of irregular architectural elements and semantic enrichment are the two crucial issues (Lo Turco et al, 2017). While pure modelling software was born to model primarily in the NURBS environment, parametric software is born BIM-oriented precisely because of the possibility to control it operates over the regular built environment (Bacci et al, 2019). The former must solve the lack of information needed by the model; the latter seek greater correspondence to the irregular shape. In this context, NURBS curves can be an efficient solution for modelling irregular architectural elements by allowing curves and surfaces of complex shapes to be represented with accuracy and versatility (Barrile et al, 2022), but, above all, mathematically controlled manner; in addition, the use of NURBS curves allows faster modelling, objects can be created more quickly than traditional modelling techniques by using algorithms that are adapted to different case studies.



**Figure 1.** The neo-Gothic tower point cloud in the environment.

Our research question grows in this area and involves three ways of modelling a neo-Gothic tower (Figure 1) to be imported into a parametric BIM software starting from an accurate point cloud. The tower is one of the ancient buildings of a monumental park in Lombardy region, not far from Milan. It is joined to a two-story rectangular building with side porch and it has a belvedere at the top made of stones (Gatti Perer, 1996). The roof of the west body is pitched in brick tiles supported by rafters on walls. The modelling workflows will be compared to define accuracy, insertable information, and speed of realization.

Finally, future developments of NURBS curves in BIM and their possible evolution will be discussed.

### 1.3 Relevance

The proposed issue has a threefold relevance; the commercial parametric software mainly used for HBIM can provide many tools by inserting additional information within the tables of linked Data Bases. However, this method leaves the geometric model far from the shape definition given by the point cloud originally surveyed: the model could be standardized and considered a sort of box of information. While the gap between NURB oriented software and BIM software is not satisfactorily bridged, other avenues are developed to model Cultural Heritage: some research relate to the annotativeness of the surveyed cloud (Murtiyoso, 2019), others use Machine Learning (Croce, 2021) to segment part of the point cloud and use the recognized objects not to lose accuracy in its translation into a BIM model. The speed of the transformation of the acquired cloud into an accurate model becomes a relevant parameter. Heritage-oriented BIM libraries could be hypothesized, with parametric and editable objects for different models but with several variants that are difficult to manage. All these reasons are what drive the definition of the process of meeting the NURB and BIM modelling environments to a development toward the integration of one over the other, as there are many considerations open in their never actually completed process.

## 2. PROPOSED SOLUTIONS

The proposed case study concerns a Visconti Tower, built by Luigi Canonica in the first two decades of the 19th century, during his work at the gardens of the Villa Reale in Monza. The building, attached to a main body also made of brick and blocks of a stone called "Ceppo" has the shape of a cylindrical element with a strong tapering towards the top, made of bricks of different sizes; this will be used to compare the pros and cons of different modelling workflows.

The surveying phase has been developed with Leica RTC360 laser scanner, a static laser able of acquiring scans of 2 million points per second and HDR image; through an internal VIS (Visual Inertial System) automated targetless field registration is possible. In this way, phenomena of object splay, tapering and out-of-plumb are accurately detected and returned.

After target-less pre-alignment in the proprietary Cyclon FIELD application, an additional alignment phase was performed in the proprietary Cyclone REGISTER 360 software, followed by a cleaning phase of the 10 set ups. The outcome is a point cloud with a total of 461,086,484 points with an error of 0.003 m.

The tower was exported in .e57 format, isolated from the context and regular masonry elements, easily modelled in BIM software, in order to avoid point interference in modelling.

The cutting of the tower from the context is achieved through the use of the open source software Cloud Compare allowing to reduce the data from 460 mln points to 443,164; then the cloud is further cleaned from improper points and decimated through distance parameters of 0.01 m between the points for a regular definition of a grid geometry so as to cancel overlaps and redundancy of the data and have a grid of points as regular as possible.

Several point clouds with different degrees of decimation were created to experiment with the most suitable and compliant one in terms of data heaviness and accuracy in describing the architectural element. The range goes from detailed clouds of 26,971 points to clouds with high degrees of decimation reducing the points down to 5,464.

The .e57 format is chosen for its interoperability characteristics and entered into Rhino modelling software, Several experiments have been developed to work out a workflow that is based on the development of NURBS to compare different geometries through modelling processes between manual and semi-automated ones based on the use of different algorithms.

### 2.1 Patch workflow

The first workflow is based on managing the geometric level of the point cloud within Rhino modelling software via NURBS using the Rhino Patch command.

The goal is to create a workflow that can faithfully return the geometry of the tower through modelling based on data linked to manually entered points and profiles in Rhino.

The decimation of the point cloud was brought on with a distance of 0.05 m, in order to have a good description of the tower geometry but avoid making the modelling process more cumbersome; patch modelling is better with a reduction of the given point in order to avoid overhangs and deformations.

To avoid deformations due to the circular shape of the tower, it was decided to segment the point cloud into parts by further reducing the point cloud to 1,977 points.

The point cloud turns out to be a regular grid, the modelling area is delimited by a series of polylines, the "patch" tool allows the generation of a surface adhered to the points.

Despite the workflow has an accuracy level of 0.01 m and respects the margin of tolerance in modelling the surface, it presents limitations (Figure 2).

The circularity of the building creates deformations and overhangs in the generation of the patch by imposing an additional division into half-cylinders that make it difficult to model the entire element.

The object also is categorized through Revit families but nominally, this implies a limitation as the association remains nominal and purely formal (Figure 3).

The wall element is described by a surface to which no thickness is associated; this turns out to be a limitation and despite the fidelity and degree of detail, it can be described only geometrically and nominally.

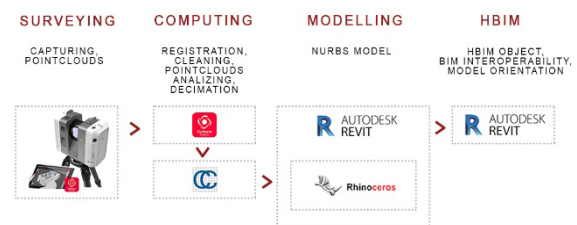


Figure 2. The workflow of the Torretta Viscontea with the Patch modelling system.



**Figure 3.** Comparison of adherence between point cloud and patch surface.

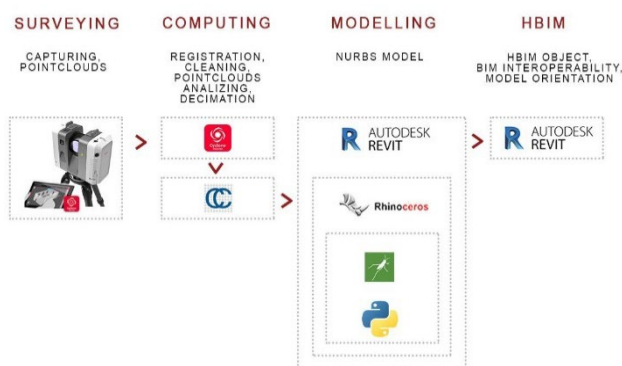
## 2.2 NURBS Modelling through profiles.

The second workflow uses "Rhino inside Revit" plugin through an algorithmic procedure in Grasshopper to correctly describe both the geometry of the tower and the association of materials. The goal is to create a model derived from a series of horizontal sections to correctly describe the different out-of-plumbs of the walls and to create a more innovative, performant, and semi-automated modelling process to integrate the abilities of Grasshopper, Rhino, and Revit (Figure 4).

The goal is to obtain an accurate geometric description based on profiles that through the integration of parametric modelling systems allows association to a Revit material and its thickness. The point cloud of 26,971 points is inserted into Rhino and cross profiles of the tower are created following its geometry with circles, polylines, curves.

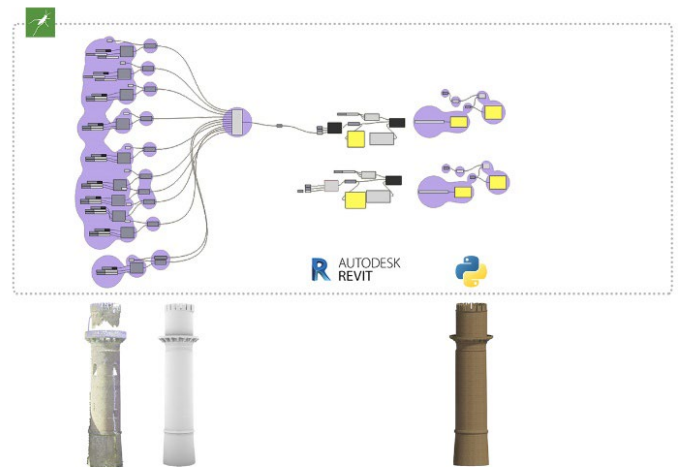
The profiles were positioned at the points of variation of the tower geometry to describe the changes in inclination and the different architectural elements, with a maximum distance of 1 m in the points of regularity.

Create the "curves" that return the geometry of the point cloud is associated with the "loft" node to create a uniform surface passing through the curves.



**Figure 4.** Workflow of the Torretta Viscontea with the NURBS modelling through profiles.

The element is directly inserted into Revit thanks to a specific algorithm that allows the association of the element to the family "wall" and "type properties". In this, a Revit stratigraphy is associated with the wall geometry modelled in Grasshopper, thanks to a script in Python that allows its rapid association (Figure 5).



**Figure 5.** Algorithmic process diagram in Grasshopper for modelling.

This method has great potential; it allows to overcome any gaps in the point cloud, building an element with a unique surface passing through points defined at the start.

It also offers the great advantage of material association between Rhino and Revit, making the "wall" element a true parameterized element in Revit with certain characteristics in the "Type Properties" including:

- Construction (Texture, Folding around inserts, Folding at ends, Width, Function)
- Cross section properties (Default outer angle, Default inner angle, Width)
- Graphics (Low detail screen, Low detail screen color)
- Identity data (Type comments, URL, Description, Assembly description, Assembly code, Type marking, Fire resistance, Cost).

The limitation of this process turns out to be the degree of approximation derived from the points between the different profiles, which does not guarantee a detailed description of the different overhangs and out-of-plumbs, respecting a good degree of accuracy in 60% of the modeling while maintaining a degree of tolerance below 0.015 m and the remainder with a margin of 0.05 cm 8 (Figure 6).

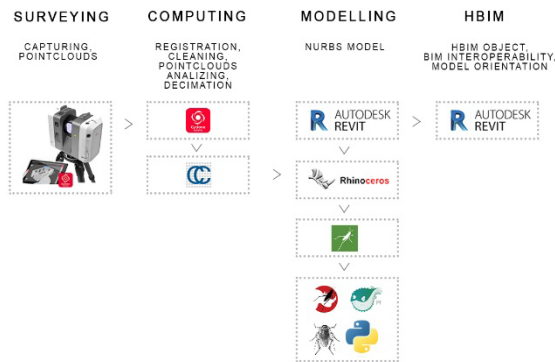
This workflow allows overcoming the geometric limitations of parametric modeling in favor of a more flexible NURBS-based method while retaining the advantage of Revit family parameterizations.



**Figure 6.** Comparison of adherence between point cloud and profiles surface.

### 2.3 NURBS modelling through meshes.

The third workflow uses the "Rhino inside Revit" plugin through a Grasshopper algorithmic procedure as well. The goal is to experiment a workflow that relies on automated modelling through the integration of Grasshopper, Rhino and Revit in order to create accurate geometry through an automated process that relies on point modelling (Figure 7).



**Figure 7.** Workflow of the Torretta Viscontea with the NURBS modeling through meshes.

After having imported the point cloud of 20,000 points in Rhino through the Cockroach plug-in in Grasshopper, it is associated with the "point cloud" node to insert it into the algorithm by defining its origin, position, and points.

A first step has been defining the point normal to work out the direction of the mesh and its generation.

Cockroach is a Grasshopper plug-in specialized in the management, segmentation, decimation, analysis and modelling of meshes from point clouds.

A series of simplifications of the geometric mesh has been developed thanks to Pufferfish and Flexibility, plug-ins of Grasshopper, that can effectively handle degrees of curvature and complex geometries of the mesh and transform the mesh triangles in more simplified grid geometric elements without losing the degree of detail (Figure 8).

Through "Quadrimesh," "SubD," and "SubDtoNURBS" nodes, a uniform surface adhered to the point cloud is obtained.

Through Revit commands within Grasshopper the wall family, "type properties" are assigned with the goal of associating a particular type of masonry.

Through the Python plug-in in Grasshopper through a code snippet the association between elements is generated to avoid manual selection of each part of the NURBS.

As in the previous workflow there is then the possibility of association between surface and masonry element making the latter a real parameterized element in Revit with certain characteristics in the "Type Properties" including:

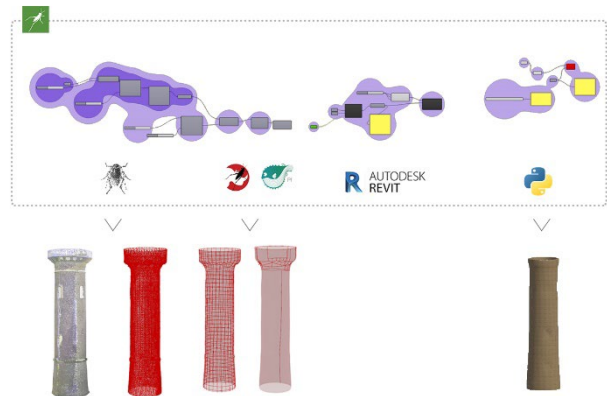
- Construction (Texture, Fold around inserts, Fold at ends, Width, Function)
- Cross section properties (Default outer angle, Default inner angle, Width)
- Graphics (Low detail screen, Low detail screen color)
- Identity data (Type comments, URL, Description, Assembly description, Assembly code, Type marking, Fire resistance, Cost)

The model turns out to have a high degree of accuracy and a good degree of tolerance due to the adherence of the mesh to the point cloud; furthermore, through the definition of a node diagram the whole process turns out to be parameterized described and based on universal mathematical and geometrical relationships that can be replicated and modified in real time. The result obtained from the comparison between surface and point cloud indicates a good adhesion with a margin of error of about 0.0097 m in 54% of the mesh (Figure 9).

Some problems appear in parts of detail such as corbels cornices and windows that turn out to be in fact unmodeled and irrelevant elements as the mesh describes the masonry.

The shortcomings related to this process turn out to be the handling of clouds with gaps in the relief that can compromise the generation of a uniform mesh, a second limitation turns out to be the segmentation in some parts of the NURBS and the complexity of its geometry.

The great potentials turn out to be the creation of irregular surfaces with a high degree of accuracy, the association of the Revit material giving a thickness of the wall element, the modeling process by algorithm and consequently conformable to any point cloud and consequently the extreme speed of the automated process.



**Figure 8.** Algorithmic process diagram in Grasshopper for modelling.



**Figure 9.** Comparison of adherence between point cloud and meshes surface.

## 2.4 Experimental evaluation

The conversion of point clouds to NURBS models and then to BIM objects is a fundamental process for the accurate representation of architectural structures in the HBIM field.

The transformation from point clouds to NURBS facilitates model creation because it uses regular curves and surfaces instead of isolated points. The use of BIM objects allows the integration of useful information such as geometric, constructive, textural, functional, informational, and descriptive data.

The importance of the Rhino Inside Revit plugin as a tool for associating NURBS with BIM objects lies in its ability to combine the power of Rhino modeling software with Revit BIM software, creating a more efficient and integrated workflow.

The use of Rhino opens the possibility in the management of NURBS both in the field of more traditional and manual workflows as in the first case through redrawing and patching, but more importantly the possibility of using algorithmic modeling workflows thanks to the Grasshopper plug-in.

The use of Grasshopper offers great possibilities in terms of creating automated processes and algorithmic diagrams that can overcome traditional modeling of each individual element in favor of automatic generation of simplified meshes.

Grasshopper offers a range of open-source plug-ins capable of solving the problems associated with modeling particularly complex elements.

The plug-ins within Grasshopper turn out to be extremely flexible, focused on different issues capable of overcoming modeling limitations: Volvox and Cockroach are suitable for point cloud management, decimation, and segmentation; Pufferfish and Flexibility are able of effectively handling degrees of curvature and complex geometries, while Python is a scripting language that enables automation of the association process.

The study highlights the enormous potential related to interoperability between NURBS and BIM management software in the creation of models with varying degrees of parameterization and automation of processes, of open-source plug-ins able to solving problems related to the modeling of particularly complex elements.

## 3. CONCLUSION

From a comparison of the different workflows (Table 1) in the following table, it is evident that the more manual and traditional Patch system based on point and profile data processing has limitations in processing objects in the round.

The workflow, which is optimal in the creation of planar irregular surfaces such as vaulted ceilings, despite the accuracy appears ineffective in the case study of the Visconti tower; moreover, the only nominal association limits the effective interoperability between NURBS and HBIM leaving the object purely formal.

More performing turn out to be the subsequent workflows based on Grasshopper integration, which through algorithmic systems provides the possibility to create a masonry typology linked to type properties offering the creation of an informed and parameterized BIM object.

Both workflows are thus based on the management of various algorithms that allow a different degree of automation in modelling.

This aspect turns out to have pros and cons; in fact, if on the one hand the accuracy of modelling through profiles is less accurate and with longer timeframes, on the other hand relying on a series of horizontal sections any gaps in the point cloud are not an issue. The workflow that is based on the creation of a mesh turns out to be the most efficient with a methodology based on the use of algorithmic systems capable of directly processing the data "point" derived from the point cloud, the automated process,

from the highly performance timelines, with a high degree of accuracy.

The only issue with the workflow is related to the possible existence of gaps in the survey point cloud; because the process is fully automated it is affected by the geometry in the calculation and needs segmentation to process more simplified calculation processes.

Thus, it seems clear that the profile workflow and the mesh workflow meet different needs and can compensate for any problems associated with one or the other, respectively.

Workflow	Patch	Profiles	Mesh
Point cloud	1.977 points (partial)	26.971 points (total)	20.000 points (partial)
Accuracy	0.01 m	0.02m	0.0097 m
Parametric BIM Object	Nominal	Nominal and in three dimension	Nominal and in three dimension
Link to the thickness of the wall	NO	YES	YES
Process	Manual	Semi-automated	Automated
Time for modelling	3 hours	4 hours	30 min
Limitations	Circularity	Loss of a data among profiles	Missing elements and holes in the poin clouds
Plug-ins	Rhino inside Revit	Rhino inside Revit Python	Rhino inside Revit Volvox Cockroach Pufferfish Flexibility Python
Geometry	Points, Profiles	Profiles	Points

**Table 1.** Comparison among the four workflows.

From the experimentation with the workflows, the conversion of point clouds into NURBS models and then into BIM objects is a fundamental process for the accurate representation of heritage architectures. But it is the use of Rhino Inside Revit plugin and Python as a combined tool that allows to associate NURBS with BIM objects and the automation and simplification of the modelling process turns out to represent the new challenge and approach in three-dimensional rendering of HBIM.

#### 4. CONCLUSION

From a comparison of the different workflows in the table, it is shown that the more manual and traditional Patch system based on point and profile data processing has limitations in processing objects in the round.

The workflow, which is optimal in the creation of planar irregular surfaces such as vaulted ceilings, despite the accuracy appears ineffective in the case study of the Visconti tower; moreover, the only nominal association limits the effective interoperability between NURBS and HBIM leaving the object purely formal. More performing turn out to be the subsequent workflows based on Grasshopper integration, which through algorithmic systems provides the possibility to create a masonry typology linked to type properties allowing the creation of an informed and parameterized BIM object. This path opens to new possibilities to speed up workflows and give more informed results.

#### 5. FUTURE RESEARCH

Future research on informed modelling should increasingly deal with interoperability between platforms.

Since the advent of Dynamo as a specific modeler for complex volumes in Revit, research has polarized toward the interaction between the new internal model extensions offered by Grasshopper and Rhino, and related apps. Easily this has deferred to a range of further possibilities that are likely to be absorbed within the main platform and future research will help, with all attempts the development of increasingly agile workflows.

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#### REFERENCES

Adami A., Appolonia L., Scala B., 2021. The Arch of Augustus in Aosta: data and analysis reuse. *Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES*.

Bacci, G., Bertolini, F., Bevilacqua, M. G., Caroti, G., Martínez-Espejo Zaragoza, I., Martino, M., and Piemonte, 2019. A.: Hbim methodologies for the architectural restoration. The case of the ex-church of San Quirico all'Olivo in Lucca, Tuscany, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W11, 121–126, <https://doi.org/10.5194/isprs-archives-XLII-2-W11-121-2019>.

Barrile, V.; Bernardo, E.; Bilotta, G., 2022. An Experimental HBIM Processing: Innovative Tool for 3D Model Reconstruction of Morpho-Typological Phases for the Cultural Heritage. *Remote Sens.* 2022, 14, 1288. <https://doi.org/10.3390/rs14051288>

Bianchini, C., Nicastro, S., 2018. La definizione del Level of Reliability: un contributo alla trasparenza dei processi di Historic-BIM. In: Dienne, Building Information Modeling, Data & Semantics.

Capone, M. and Lanzara, E., 2019. Scan-to-bim vs 3d ideal model hbim: parametric tools to study domes geometry, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W9,

219–226. <https://doi.org/10.5194/isprs-archives-XLII-2-W9-219-2019>.

Chiabrando, F., Lo Turco, M., and Rinaudo, F., 2017. Modeling the decay in an hbim starting from 3d point clouds. a followed approach for cultural heritage knowledge, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W5, 605–612, <https://doi.org/10.5194/isprs-archives-XLII-2-W5-605-2017>.

Croce, V., Caroti, G., de Luca, L., Piemonte, A. Véron, et al, P., 2021. Artificial Intelligence and H-BIM for the Semantic Description of Cultural Heritage: the Pisa Charterhouse. *42e Conférence internationale des enseignants des disciplines de la représentation*, Reggio Calabria, Italy.

Gatti Perer, M.L., 1996. La torretta dei Giardini reali. SIRBeC: <https://www.lombardiabeniculturali.it/architetture/schede-complete/MI230-00106/> visited 01 April 2023.

Lo Turco, M., Mattone, M., and Rinaudo, F.: metric survey and bim technologies to record decay conditions, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-5/W1, 261–268, <https://doi.org/10.5194/isprs-archives-XLII-5-W1-261-2017>, 2017.

Murtiyoso, A. and Grussenmeyer, P.: Point cloud segmentation and semantic annotation aided by gis data for heritage complexes, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W9, 523–528, <https://doi.org/10.5194/isprs-archives-XLII-2-W9-523-2019>.

Ori L., 2021, Ottimizzazione della metodologia HBIM applicata al progetto di restauro architettonico, in HBIM e Geomatica per i beni culturali, Milano, 2021, pp 110-127.

Rocha, G.; Mateus, L.; Fernández, J.; Ferreira, V., 2020. A Scan-to-BIM Methodology Applied to Heritage Buildings. *Heritage* 2020, 3,47-67. <https://doi.org/10.3390/heritage3010004>

Spallone, R., Vitali, M., and Natta, F.: 3d modelling between ideation, geometry, and surveyed architecture: the case of the vaulted system of 'appartamento di mezzanotte' in palazzo Carignano, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W15, 1119–1126, <https://doi.org/10.5194/isprs-archives-XLII-2-W15-1119-2019>.