ISSN 1828-5961

Luca Rossato
Architect, PhD, since 2022 is assistant professor RTDb (SSD ICAR/17) at the Department of Architecture, University of Ferrara. His interest in modernist architecture led him to found the international research network I N S I D E Modern Heritage, for which he's scientific director. He is member of the Italian Union for Drawings UID since 2017 and member of ICOMOS.

Fabio Planu
PhD Candidate at the University of Ferrara. He carries out research activities at the DIAPReM and at the Tekne-Hub Laboratory, in the field of solutions for 3D survey methodologies and processes and representation in BIM. He is involved in industrial research projects about the integrated representation and management of the built environment over time.

Greta Montanari
PhD Candidate at the University of Padua, Department of Civil, Environmental and Architectural Engineering, concentrating on the digitization of the survey of small urban centers of historical-artistic value. She also collaborates with the Architecture Department Research Centre of Ferrara.

Dario Rizzi
PhD Candidate at the University of Ferrara. He carries out research activities at the DIAPReM, and he is focused on BIM representation and development of new metholodoly. He is specialized in survey's projects about heritage and complex buildings.

The Rocca Malatestiana of Verucchio SCAN to HBIM process for the digitisation of cultural site with severe topography condition

The essay highlights the process of three-dimensional acquisition and digitisation through HBIM of the Rocca Malatestiana of Verucchio, in the Rimini area. The case study presented is set in a context strategically located on a hill overlooking the Marecchia river valley with high orographic and interpretative difficulties due to the different overlapping historical layers. The Malatesta Fortress of Verucchio, which is built on a number of levels to accommodate the terrain's orography, is perched atop the towering pinnacle of a rocky spur that dominates the Marecchia valley. Due to its location nearly 300 meters above sea level, overlooking the Adriatic Sea and the Apennines, the fortress—a symbol of the Malatesta family's power—became a crucial strategic and defensive hub. It served as the main seat of Malatesta power along the coast and in the Marche region for centuries.
The research group involved in the project of integrated three-dimensional survey and digitisation through BIM of the building of the Rocca di Verucchio has worked to give back to the small municipality a model for the management of the rich heritage of the place.
The integrated scanning and HBIM implementation process has resulted in a coherent and highly informative digital model of the material, historical and typological conformation of the various parts of the artefact. The Verucchio case study exemplifies how the development of digital representation systems for architectural heritage is a field that is constantly evolving and is currently a focus of interest and innovation for all players in the field.

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

INTRODUCTION

In light of the growing interest in historic architectural heritage on a European level as a strategic asset for socioeconomic development growing interest and experimentation are being made in the area of digital documentation of already-built heritage. This is especially true thanks to the use of BIM, which is being used to develop and optimize 3D documentation protocols and develop comprehensive data models and digital representation models. By incorporating information on the structure of the building, the materials used in its construction, and the original architectural characteristics, BIM models enable the creation of a complete digital representation of the historical building.
The use of BIM in the context of digitally documenting existing built heritage supports a greater degree of automation in information gathering, processing, and sharing processes, which makes it easier to create databases and drawings even in almost inaccessible contexts.
The research team involved in the project for the digital documentation of Rocca di Verucchio's building has been working to provide the small municipality with a model for managing the rich local heritage.
This contribution, after a brief description of the case study, resulting from the analysis of the little existing bibliography on the subject, focuses on the activities of acquisition carried out along the on-field campaign. As described in this part, the Rocca Malatestiana of Verucchio database sees two coherent point clouds that are georeferenced. Leica BLK360 technology was used for the first task (laser scanning) which allows for quicker movement and stationing, shorter acquisition periods, and the combination of metric and colour data. The building on top of the citadel, the clock tower on the courtyard side, the courtyard itself, and all the internal rooms were all surveyed using this technique linked to the topographic net built using a Total Station - Leica TPS 1202. A DJI mini 2 UAS drone was used in a photo acquisition campaign that yielded the second, photogrammetric, output.
The large amount of data fused into a very large point cloud made it possible to start post-processing the data by implementing an HBIM model.
The essay illustrates also this step explaining how the Mastio Tower, the Great Hall and the prisons, the part to the east with the clock tower, and the topography data were conceived as four independent but coherent models. These three-dimensional databases are connected with the same references level in the HBIM model in order to address the morphological complexity of the Fortress.
Each model and each point cloud used to produce the models are georeferenced in accordance with a common coordinate system, making it possible to automatically combine the files into a single federated model using the software's features.
The last part of the text addresses the issue of the 3d modelling of site with topographical complexity, describing a procedure where the contour lines may be extracted from a digital elevation model and imported into Revit to create the topographical surface was experimented with. The contour lines required to only refer to the terrain in order to complete this procedure, therefore the cloud's points had to genuinely be characteristics of the terrain from the perspective of topographical landscape representation.
Therefore, it was necessary to segment the point cloud, or to divide the points into subsets (often

Keywords:
Cultural Heritage; 3D laser scanning; SCAN to BIM; small historical centres; HBIM.

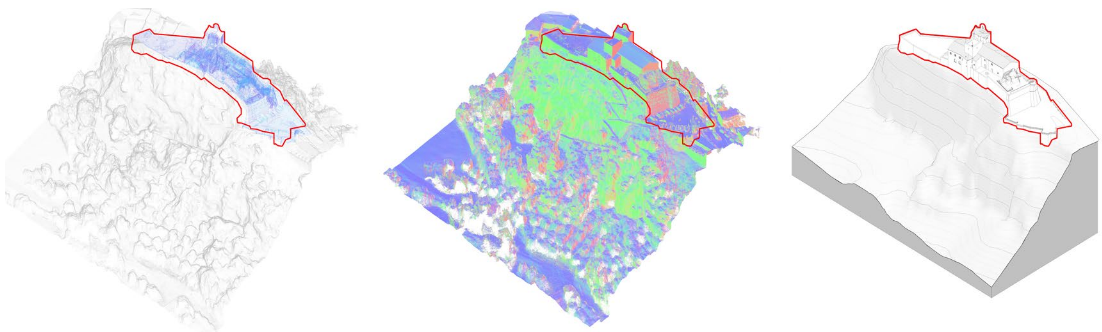


Fig. 1 - Digitisation process of Rocca Malatestiana in Verucchio (DIAPReM / TekneHub image, graphic elaborations by the authors).

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

referred to as segments) that share one or more characteristics.
The end of the contribution presents the conclusions by the authors that highlight that the lack of standardised protocols for digital representation causes a separation between the research world and the professional world, producing elaboration without a real specific standard (despite the UNI11337 standard) that can direct them.
At the same time it is stressed the importance of HBIM approach towards complex cultural heritage site to conceive conservation and management plan, reliable drawings and other output as the wooden model (at 1:50 scale) of the large building, created in the model laboratory of the University based on the plans and elevations extracted from the three-dimensional model where the components of the building were created based on laser-cut elements and assembled on the reconstructed spur itself

HISTORICAL CONTEXT

The historical context of this research is the small town of Verucchio, a minor inhabited centre, located between the sea and the hill, with a varied historical stratification that sees its moments of greatest prosperity during the Etruscan period and during the stately one under the dominion of the Malatesta family.

Fig. 2 - View of the town of Verucchio from the Rocca Malatestiana (DIAPReM / TekneHub image, graphic elaborations by the authors).

Fig. 3 - The strategic position of the Fortress allows to have a view all the way to the Adriatic See. (DIAPReM / TekneHub image, graphic elaborations by the authors).

The archeological campaigns carried out between 1893 and 1894, then resumed in 2005, witnesses the presence of a flourishing Etruscan civilization of Villanovan phase, active on the site between the tenth and seventh centuries B.C. C.: the countless archaeological finds are now in the Civic Archaeological Museum of Verucchio, where they are exposed rich funeral kits from the nearby necropolis (Von Eles, 1998).
Due of the proximity to Rimini, soon the Etruscan society was influenced by the Roman one and the town of Verucchio was gradually moved to the foot of the spur above which the village remains today. Later, also because of the barbarian invasions, the settlement returned to its original position on the top of the hill, where it developed as a real "castrum" and remained so until the advent of the Malatesta family, which occurred about 1114 AD. (Mascanzoni, 2003).
The village of Verucchio appears to have a double stratification, historical and altimetric, factors of fundamental importance with which we have been confronted during the research process because intrinsic characteristics of the case study, but despite the successive demolitions and reconstructions, the village still retains its medieval urban structure.
The small town rises on two rocky peaks on which once stood two separate fortifications, placed as a lookout of the ancient road that led from Rimini

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

ISSN 1828-5961

and still leads to Tuscany (Berardi et al, 1970). When Sigismondo Malatesta arrived in Verucchio, one of the first changes was made on these fortifications, which were joined by a defensive wall of which you can still find traces on some of the houses.
The Malatesta Fortress of Verucchio was enlarged by Sigismondo Malatesta in the same year of construction of the defensive walls mentioned above, in 1449 (Bernardi, 2004, p. 47).
The fortress is located on the towering summit of the rocky spur that dominates the valley of Marecchia and is spread over several levels, adapting to the orography of the ground (Figure1). In the same period Sigismondo also strengthened and renewed the fortification works of Montefiore and Santarcangelo, but focused particularly on those of Verucchio (Berardi, 1970) for its peculiar strategic position
A polygonal bastion, called Porta del Sasso or Porta di Sant'Andrea, serves as access to the Rocca "del Sasso" (Fortress of the Stone), still well preserved thanks to successive restorations, one of the most important that took place between 1959 and 1960 (Bernardi et al., 1970). To describe the succession of internal and external spaces of the fortress and their peculiarity, we will borrow the words of Giuseppe Pecci, a scholar belonging to one of the noble families of Verucchio, who in his guide writes: "Once you reach the height of the Rocca you can see a hexagonal bulwark, with internal spiral staircase that goes up to the terrace: it is one of the first examples of the genus, having been built by Sigismondo Malatesta in 1449; it is quite preserved, if also amply restored in 1939. It follows the ogival gate, of fine workmanship, with squared stones, of the old fortress. The door was hidden by a brick curtain elevated by Sigismund in support of the new construction. Today's iron gate replaces two ancient gates, a cart and a rescue, defended by a moat now filled. First courtyard: open in the back and formed on the right on one side of the main tower of Sigismondo and the Palazzo del castellano. After all, the modern entrance of the Rocca del Mastino, until recently filled with earth. There is a large gallery, whose floor rests

Fig. 4 - Aerial view of the Rocca Malatestiana in Verucchio (image by DIAPReM centre/Guido Galvani).

on the living rock; a kind of large canticle with a vaulted ceiling: traces of which can be seen longitudinal walls." Continuing with the description Pecci wonders and emphasizes the beauty of the Fortress: "We are in the heart of a building that constitutes a very important example of a fortress of the thirteenth century; the other specimens of the time are nothing but shapeless ruins, while here we have precious elements of the plan and the constructive characteristics of the fort." (Pecci, 1962, p. 35). Symbol of the power of the Malatesta, the fortress became an important strategic and defense center thanks to its view of the Adriatic Sea and the Apennines, almost three hundred meters above sea level, remaining for centuries the main seat of Malatesta power on the coast and on the territory of the Marche (Larner, 1972).
In 1462 a siege ended with deception by Federico da Montefeltro decreed the end of the Malatesta domination of the fortress and following this event Verucchio passed under the dominion of the Church. Also from the architectural point of view the Rocca underwent changes, even if the exact period is not known; in fact "Some historians have attributed to Sigismondo Malatesta the construction of the two twin towers SS. Trinità and S. Andrea close to the city walls to the North-West, but at the current state of research for the study of the vents in the lower part of the tower and the comparison of construction techniques, suggest that

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

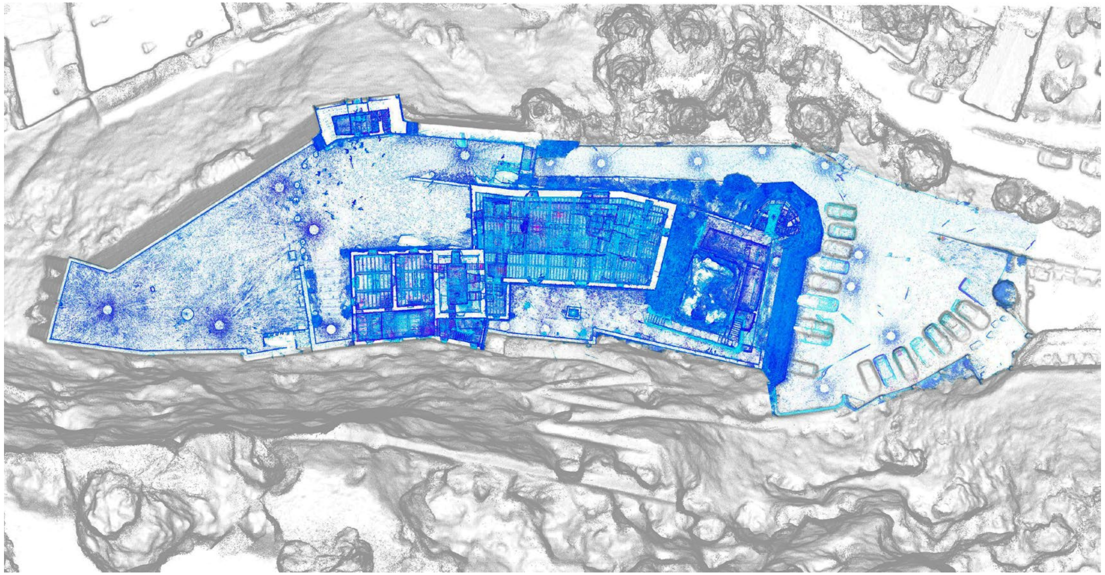
these two towers were leaning against each other in the opposite corners of the period immediately after Sigismund." (Giuccioli, 1996, p. 24.
During the 1500s the territory of Verucchio was governed by many important families: in 1500 it passed from Montefeltro to Cesare Borgia, by concession of Alexander VI, and then be governed by the Venetians three years late and by the Holy See from 1509. Seven years later Verucchio was granted as a fief to Giovanni Maria de Medici, and then finally passed to the Pio family of Carpi (Berardi et al, 1970). Later, under the domination of the church, Verucchio was named City for its economic importance (Giuccioli, 1996). Over the centuries the fortress and the buildings that include it have undergone many interventions, including those of 1696-1697 and those in 1723, going through demolitions and transformations also with regard to the intended use: in 1752 for example the Sala Magna was transformed into a theatre (Turchini et al., 2017). As G. Rimondini points out, the Fortress "is a unique and unrepeatable historical monument, a 'container' of itself, object of study that still has many secrets to reveal. In its history the changes of use have been many, from a war instrument to a stately residence... ; every new use has produced of the destructions and the modifications of the previous structures. The historical identity of the monument is also made of these structural additions." (Rimondini, 1989, p. 26).
Today the Fortress of Verucchio remains one of the best preserved Malatesta fortresses with the greater historical and cultural value (Pasini, 2013). Among the spaces of the fortress stand out for importance La Guardiola with the clock overlooking the central Piazza Malatesta, the Torre Mastio and the two elegant courtyards (Figure2). The interior rooms are also well preserved, such as the Sala Magna, in which it's located the great family tree of the Malatesta family, perfectly preserved. Finally, the bombers at the base of the towers and the prisons in the underground make this fortress a real historical museum, through which relive and explore the past in a natural context of unique beauty.

Fig. 5 - Aerial view of the Rocca Malatestiana with the clock of the tower overlooking the central square (image by DIAPReM centre/ Guido Galvani).

METHODOLOGY OF THE THREE-DIMENSIONAL DOCUMENTATION

The acquisition process was structured with a 3D digital model organised as a tool in the process of enhancing the historical architectural heritage, now an urgent need for any complex historical context (Malinverni et. Al. 2019). The increasing development of 3D laser scanner technologies and UAS systems (drones) for photogrammetric surveying allowed the creation of databases of three-dimensional morphometric information, which represent an extremely valuable tool in the cultural heritage domain (Balzani & Maietti, 2017). In the case study of the Rocca Malatestiana of Verucchio, the 3D digital model played an indispensa-

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2



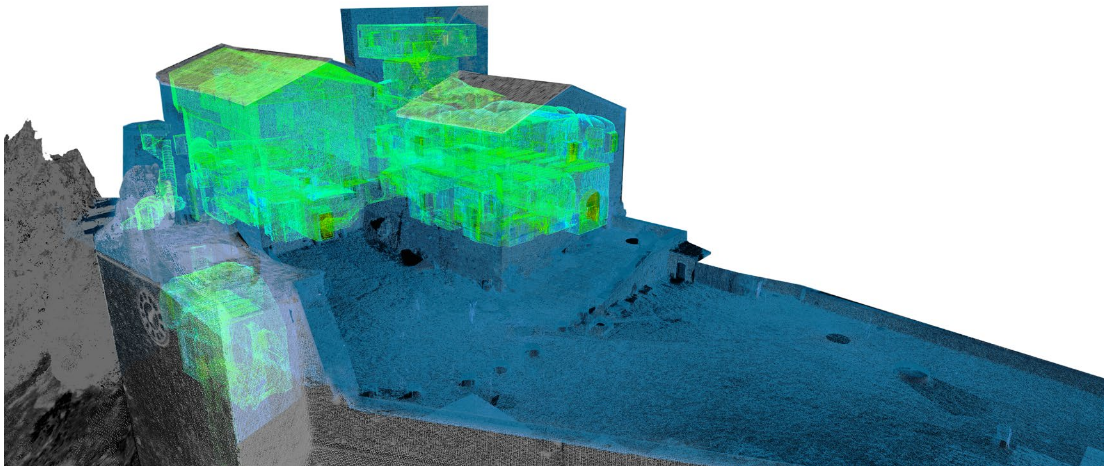


Fig. 6 - - (above) Graphic elaboration (horizontal cut) from point cloud describing the complexity of the environmental context into the which the Rocca was built aerial view of the Rocca Malatestiana with the clock of the tower overlooking the central square. (DIAPReM / TekneHub database, graphic elaborations by the authors).

Fig. 7 - (below) Rocca Malatestiana of Verucchio, visualization of the two dense 3D point clouds of the indoor spaces and external areas (DIAPReM / TekneHub database, graphic elaborations by the authors).

ble role for knowledge, with the aim of guiding the management process in the field of conservation, directing the actions related to the recovery and restoration project (Suppa, 2022). In this context, models must therefore meet requirements such as: reliability, usability and effectiveness, such as to guarantee the documentation of the built heritage in general, and specifically of the Rocca Malatestiana of Verucchio. It is therefore strategic to assess the type and scale of the survey to be carried out, analysing the context of the site, which in the case study of Verucchio presents peculiarities, analysed for the general organisation of the survey acquisition project.
The Rocca Malatestiana of Verucchio has the intrinsic characteristic of being integrated into the territorial ecosystem, being a "whole" with the cliff, where it is complex to recognise where the ramparts are integrated with the natural component (Figure3). Hence the need to detect not only the building, located on the summit, but also the historical walls, characterised by vulnerability risk, and consequently the territorial context. This condition has guided the entire integrated survey process, aimed, with different tools, at giving an integrated, complex 3D digital model of the entire territorial ecosystem with which the Fortress relates (Balzani, 2016). The result of the survey of the Rocca Malatestiana of Verucchio is a 3D digital model composed of two point clouds, georeferenced and coherent in a single coordinate system. The first, laser scanning, was carried out using Leica BLK360 technology, which allows reduced acquisition times, greater speed of movement and stationing, and association of metric data and colour data. This method was used to survey the building, located on the top of the fortress, the clock tower on the courtyard side, the courtyard itself and all the interior rooms (Figure4).
The second, photogrammetric, was the result of a photo acquisition campaign carried out using a DJI mini 2 drone. The use of UAS systems (drones) for photographic documentation for photo modelling purposes was indispensable in the case of the Rocca Malatestiana. It allowed the survey to be carried out with a field of view from both close up

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

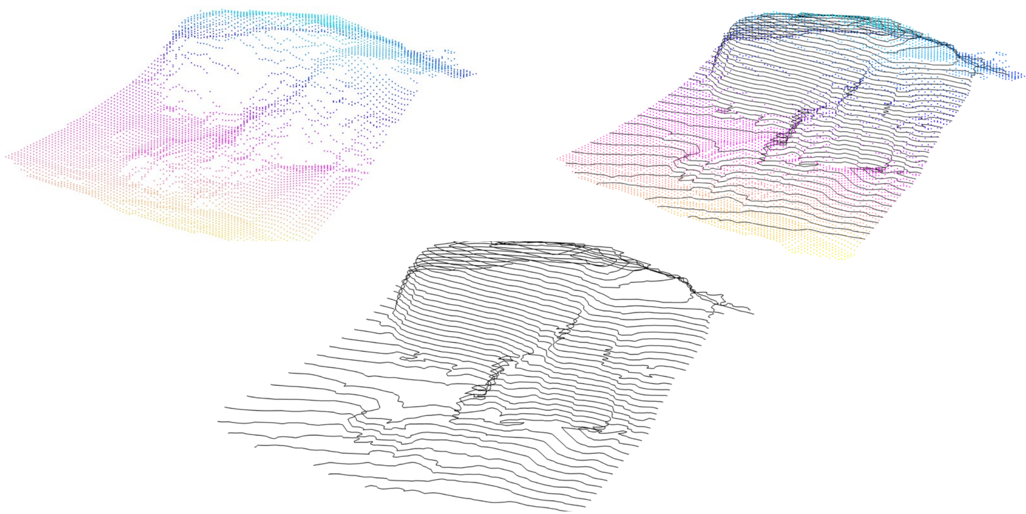
ISSN 1828-5961

and from medium and long distances (Zerlenga et al. 2023), of the parts that are not accessible with a ground-based laser scanner.
The characteristics of this technique, such as: the graphical ability not to be influenced by the material and superficial characteristics of the object, the low cost and the easy acquisition with a high resolution through a digital camera, made it possible to obtain virtual metric images of urban scenes (Barba et al. 2020), as well as spatial sections of the historical town of Verucchio, where the Rocca plays a dominant role. During the acquisition campaign using UAS systems, it was therefore possible to overcome in situ obstacles, allowing the acquisition of the clock tower, the external surfaces of the ancient fortifications, the roofs and the morphology of the rock spur.
The data collected represents a high value both numerically and in terms of accuracy. The result is a point cloud model consisting of 863.16 million coordinates of which 850 million from laser scanner instrumentation and 13.16 million from photogrammetry. The integrated survey and point cloud elaborated in such a singular context as the Rocca Malatestiana, characterised by numerous interventions and different uses from the 22nd century to the present day, constitutes the essential starting point for the subsequent three-dimensional modelling phases to allow the thematic management and sharing of the digital data at different scales. With this objective in mind, as part of the research project shared with the Municipality of Verucchio, an integrated digital survey of the Rocca Malatestiana was carried out, where, consolidated methodologies (topographic and GPS) integrated with advanced techniques (3D laser scanning and digital photogrammetry) applied (Bianchini et al. 2022) allowed the formulation of a point cloud model. An accurate three-dimensional data model that fulfils the functions of both a metric-morphological database and as a basis for the extraction of data for the detailed knowledge of the Malatesta Fortress documentation.

MODELLING OPTIMISATION OF THE ROCCA MALATESTIANA'S SPUR

The HBIM modelling of the Rocca Malatestiana in Verucchio, aimed at documentation, conservation and restoration, covered: the historic building, the ramparts and the spur. Together they constitute a unicum, making it complex to recognise where the ramparts are integrated with the natural component. Considering the purpose of the survey and the model, aimed at the acquisition and representation of the historic building, with the consolidated methodology of Scan-to-HBIM, part of the research focused on the optimisation of the modelling of the spur. As pointed out, it is complementary to the model, and essential for a coherent representation of the built heritage, as it is in symbiosis with the building, which is also characterised by underground parts.
Modelling the spur as a topographical surface directly in the Revit software, inserting the points one by one, and searching for the accuracy of the resulting mesh with the point cloud, would have been very time-consuming and would not have

Fig. 8 - Point cloud derived from DEM point creation (left), Point cloud derived from DEM point creation and contour lines (right), and (below) Vector contour lines generated in CloudCompare (DIAPReM /



DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

ISSN 1828-5961

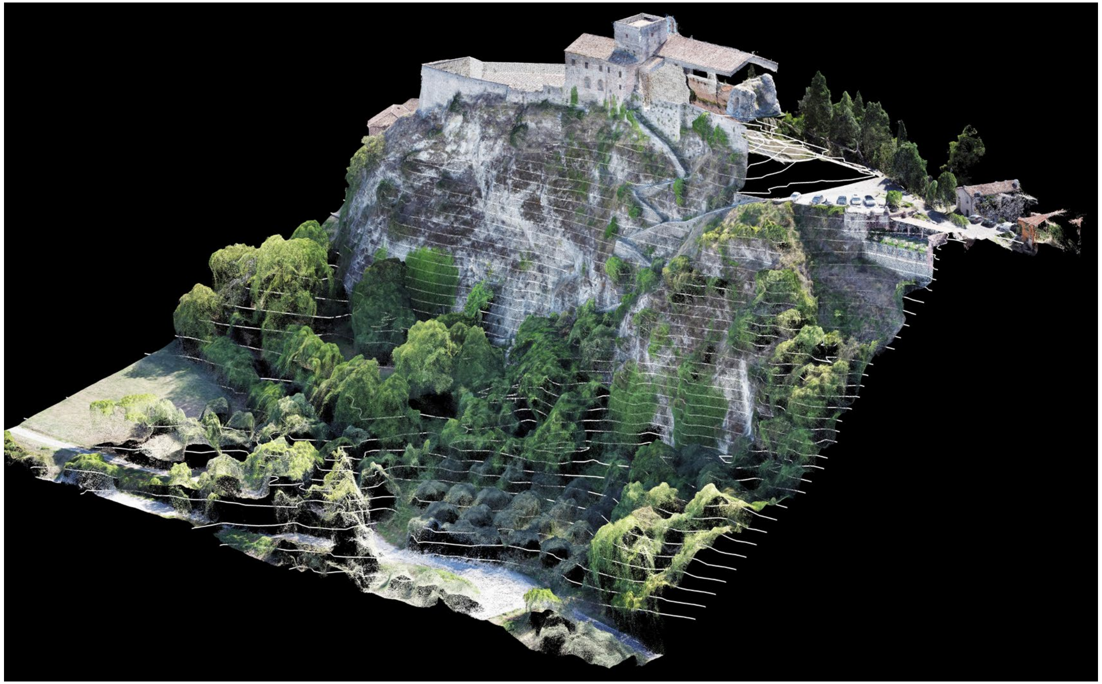


Fig. 9 - Point cloud of the Rocca Malatestiana of Verucchio derived from photogrammetry, with overlapping contour lines, (DIAPReM / TekneHub database, graphic elaborations by the authors).

guaranteed the desired accuracy. Therefore, a semi-automated method was tested to achieve the desired result, characterised by accuracy and speed of execution. Analysing the surface modelling possibilities in Revit, the aim was to generate vector contour lines directly from the point cloud. Contour lines are lines, the location of points that all have the same elevation, and are characteristics of the terrain, describing its elevation and orography. A process was therefore experimented with where, through the creation of a digital elevation model, it was possible to extract the contour lines to be imported into Revit, for the generation of the topographical surface. In order to do this process, from the point of view of the topographical terrain representation, the contour lines had to refer exclusively to the terrain, therefore the points of the cloud had to be actually characteristic of the terrain. It was therefore necessary to segment the point cloud, i.e. to group the points into subsets (usually called segments) characterised by one or more features in common (Grilli et al. 2017). In the specific case of Verucchio, all the points that, from a semantic point of view, do not constitute the topographical surface were eliminated, i.e.: trees, the rampart, the historical building, people, cars, etc. From the CloudCompare software, a DEM - Digital Elevation Model was created where, through interpolation, a homogeneous digital terrain model was obtained. The result is a point cloud derived from the creation of points from the DEM, which correspond to physical points in the terrain, i.e. the point cloud of the previously processed Rock. Vector contour lines were then generated, which were exported and saved in *dxf format, supported by Revit for the creation of the topographical surface from an imported instance (Figure5).
From Revit, it was then possible to add any points and modify the elevation of those imported, with the aim of achieving high accuracy with the point cloud in the cliff modelling process. The result of the process described thus allowed the modelling of the spur to be optimised, meeting the requirements of accuracy and speed of execution, related to the purposes of the HBIM model.

THE HBIM MODEL AS A PROCESS OF DOCUMENTATION AND MANAGEMENT OF HISTORICAL HERITAGE

The use of assisted two-dimensional drawing software is still widespread, especially for public clients, however there are an increasing adoption of Building Information Modelling (BIM) tools and methods to manage interventions on existing structures. (Raco, Rizzi, Giau, Galvani, 2020).
The process of representing historic buildings within a BIM environment, therefore, on the one hand takes into account a source of general information, composed of writings and architectural standards, but on the other hand it must take into consideration the irregularity of the architectural forms , caused both by the artisanal nature of their creation and by the damage caused by the passage of time (Brusaporci et al. 2018), characteristics that make a building unique and unrepeatable (Bianchini et al., 2016).
The Scan to BIM procedure applied to the Rocca di Verucchio saw, after the generation of the point cloud through the integration of cameras and scanning devices (Figure6), its completion using point cloud processing software (Autodesk Recap), and was imported into modelling software (Autodesk Revit). In Revit, the modelling logic was to create "local models" only where necessary, and then subsequently transform them into families, in order to have the possibility of inserting the parameters necessary for managing the mod-

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

ISSN 1828-5961

el and the building. This procedure provides a detailed and accurate representation of the existing structure, which can be used for a wide range of purposes, including renovation planning, engineering design and safety analysis.
To respond to the morphological complexities of the Fortress, the HBIM model consists of a coordination model, within which four independent but coherent models are connected with the same references level: the Great Hall and the prisons, the Mastio Tower, the part to the east with the clock tower and the topography. Each model and each point cloud used to create the models are georeferenced according to a common coordinate system which allows, using the software's tools, to merge the files automatically into a single federated model that could be use also for topographic analyses (figure 7).
This possibility of deconstruction and reconstruction allows to go into detail in the modelling by increasing the LOG of the individual components, faithfully referring to the point cloud, and to simultaneously have general control of the entire volume of the building. A secondary advantage is the possibility of controlling the informatic weight of the files, this often secondary aspect is actually necessary to have a manageable and fluid navigation file. The choice of model weight must be a specification defined at the start of modelling and defined based on the reference LOD (Bianchini & Nicastro 2018). For all the models created it was decided to increase the level of geometric detail (LOG) and not to implement the information level (LOI). To create all the models we started from the generation of the common levels and then proceeded with the tracing of the main system elements and then the further components necessary to describe the building.
A particular focus was made on the creation of the Rocca, the topography model that takes into account the context around the building to provide the local municipality with complete set of drawing for multi purposes use (Rodriguez-Navarro, 2017). To create the model, the photogrammetric point cloud produced by the drone was manually segmented, eliminating everything extraneous to the

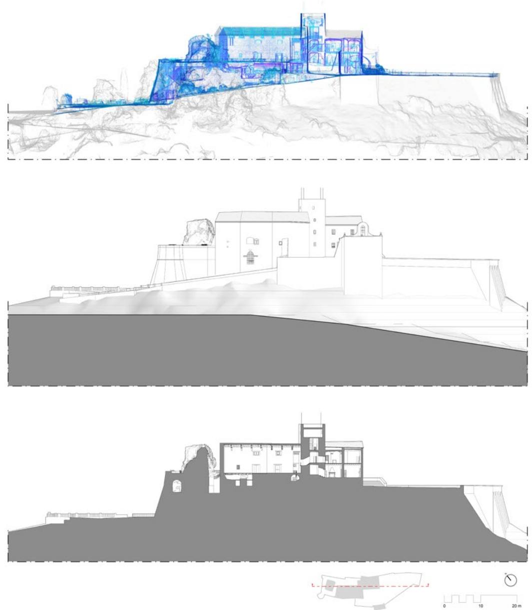


Fig. 10 - (above) From point cloud (top) to the HBIM model and finally the 2D drawings obtained enquiring the database (DIAPReM / TekneHub database, graphic elaborations by the authors).

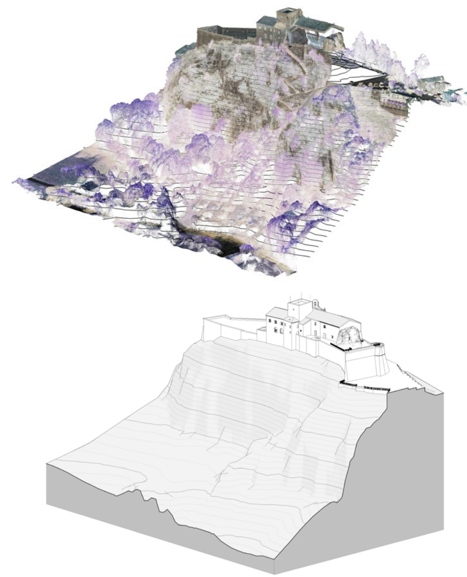


Fig. 11 - (right) Result of terrain modelling in the HBIM model of the Rocca Malatestiana of Verucchio, from contour lines created in CloudCompare (DIAPReM / TekneHub database, graphic elaborations by the authors).

terrain. Then, using the CloudCompare interpolation algorithm, the gaps generated by the previous processing were filled and the three-dimensional level curves were generated. It was therefore possible to export them in *dxf format and produce a mesh which was then imported directly into Revit for the three-dimensional reconstruction of the topography. This solution allowed us to return the three-dimensional mesh consistent with the point cloud, as "point by point" modelling would have been more complex and less precise from a morphological point of view (Figure8).
In addition to this method, further avenues were investigated but considering the purposes of the model it was preferred to directly import a mesh consistent with the level curves. A further method analysed for generating the fortress started from the default Revit tools, the use of the topography command. Starting similarly from the segmented and interpolated point cloud, a mesh is generated and exported in *dxf format. Then, we proceed

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

with the import into Revit, being a file readable with 3D CAD it is read by the topography tool as a basic element for inserting all the points necessary for the creation of the Revit topography. Finally, it is possible to delete the mesh and manage the points individually within Revit.
Both methods generate, in different ways, a similar product. The substantial difference is the timing for the creation of the models and their precision. In the method used, the first, you have a very precise model with a detailed graphic rendering that best describes the fortress and consequently the building, while in the second case, despite the speed of creation, a less precise model is obtained. In this case study the Fortress is a fundamental element and integrated part of the building and it was decided to create a model as faithful as possible to reality in order to produce reliable 2D drawing that were transferred to the local municipality (Figure9). The second method used for wider and less steep terrain was certainly more functional for the creation of the context.

FINAL REMARKS

The case study of Verucchio demonstrates how the evolution of digital representation systems of the architectural heritage is an area in continuous evolution and currently an area of interest and innovation for all operators in the sector. Among its numerous and multifaceted potentialities, the BIM. includes, for example, those of diachronic and multiscale management of digital models (Spallone et al., 2016) particularly useful in cases such as that of the Verucchio Fortress. At the same time, the digital model can be used to simulate museum set-ups in different rooms or maintenance and restoration work on pre-existing surfaces (Figure10). Considering the management of architectural heritage information, there is a distinguishing factor that does not exist in any other field: a multilevel spatial character in the third (or even fourth) dimension. Furthermore, the semantic enrichment of three-dimensional (3D) digital models through the integration of heterogeneous

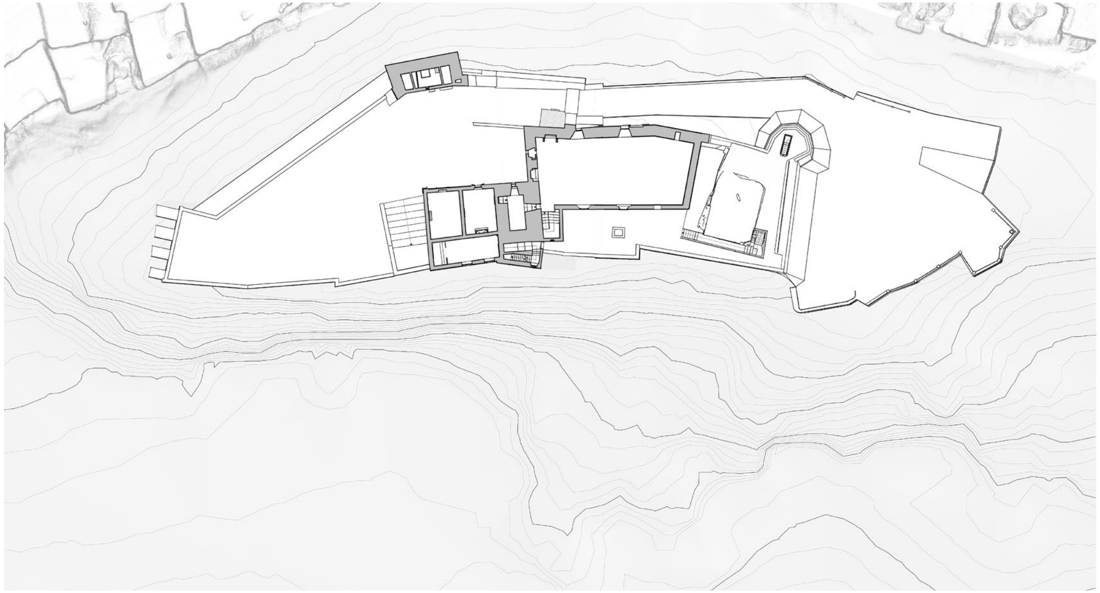


Fig. 12 - (left) Plan of the main level of the Rocca Malatestiana of Verucchio (DIAPReM / TekneHub database, graphic elaborations by the authors).

Fig. 13 - (above) digital elaboration of Verucchio cultural heritage form the 3D database (DIAPReM / TekneHub database, graphic elaborations by the authors).

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

data sets is of crucial importance. However, the organisation and structuring of such information is considerably difficult, although it is very useful for better preservation and management (Saygi & Remondino, 2013).
The lack of standardised protocols for digital representation causes a separation between the research world and the professional world, causing them to travel on parallel roads without any real specific regulations (despite the UNI11337 standard) to direct them. This often leads to digital models that are inconsistent and full of setting errors, causing confusion and preventing automatic data exchange. Furthermore, the use of IFC models, which are necessary for passing data between different software, is still difficult and without a common modelling protocol, much information is bound to be lost. It is therefore important that the research and professional worlds work together to develop standardised and shared protocols that can help build accurate and reliable digital models even for those smaller historic centres that often suffer from social and economic isolation.

PROJECT CREDITS

The research "Definition of protocols for the integrated digital, geometric-morphological survey and HBIM modelling of the cultural heritage located in Verucchio, with particular reference to the Rocca Malatestiana and the Civic Archaeological Museum of Verucchio, by means of integrated three-dimensional survey and digital modelling technologies, aimed at the knowledge, documentation and modelling for the technological transfer and integrated management of the cultural heritage" was conceived by the Municipality of Verucchio and the Department of Architecture, University of Ferrara, DIAPReM/TekneHub Laboratory.
Scientific coordinators: for the Department of Architecture, University of Ferrara, DIAPReM/TekneHub Laboratory, Prof. Marcello Balzani and Dr. Fabiana Raco; for the Municipality of Verucchio, Engineer Marino Pompili, Head of the Technical, Culture and Sport Sector.
DIAPReM/TekneHub research group: responsible for the survey and processing of the overall data model arch. Guido Galvani. Research group: Fabio Planu, Luca Rossato, Dario Rizzi, Greta Montanari, Gabriele Giau, Federica Maietti, Francesco Viroli.

AUTHORS CONTRIBUTION

Luca Rossato wrote the chapters "introduction" and "final remarks";

Fabio Planu wrote the chapters "Methodology of the three-dimensional documentation project" and "Modelling optimisation of the Rocca Malatestiana's spur";

Greta Montanari wrote the chapter "historical context";

Dario Rizzi wrote the chapter "The HBM model as a process of documentation and management of historical heritage".

All the images were elaborated by the authors from the original ones of the DIAPReM/Teknehub database
research

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2

ISSN 1828-5961

REFERENCES

Balzani, M. (2016). Il rilievo tridimensionale dell'Istituto degli Innocenti. in Mulazzani, M. *L'Ospedale degli Innocenti di Firenze: la fabbrica brunelleschiana, gli Innocenti dal Quattrocento al Novecento, il nuovo museo: il progetto di recupero e l'allestimento di Ipostudio* (pp. 63-69). Milano: Electa.

Balzani, M., Maietti, F. (2017). Architectural Space in a Protocol for an Integrated 3D Survey aimed at the Documentation, Representation and Conservation of Cultural Heritage. *Diségno, (1),* 113–122.

Barba, S., Parrinello, S. Limongiello, M., Dell'Amico, A. (2020). *D-SITE, Drones – Systems of Information on culTural hEritage. For a spatial and social investigation.* Pavia: Pavia University Press.

Berardi D., Cassi Ramelli A., Foschi M., Montevecchi F., Ravaldini G., Venturi S., (1970). *Rocche e castelli di Romagna.* Bologna: Edizioni Alfa.

Bernardi, L. (2004). *Verucchio, guida storico-artistica illustrata.* Rimini: Pazzini Editore.

Bianchini C., Inglese C., Ippolito A. (2016). Il contributo della Rappresentazione nel Building Information Modeling (BIM) per la gestione del costruito. *DISEGNARE CON, 9(16)*, 10.1-10.9.

Bianchini C., Nicastro S. (2018). La definizione del Level of Reliability: un contributo alla trasparenza dei processi di Historic-BIM. *«Dn», 2/2018*, 46-60.

Brusaporci, S., Maiezza, P., & Tata, A. (2018). A framework for architectural heritage HBIM semantization and development. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42(2).*

Giuccioli, M.G. (1996). *Guida alla Rocca Malatestiana di Verucchio.* Rimini: Pazzini Editore

Grilli, E., Menna, F., and Remondino, F. (2017). A Review of Point Clouds Segmentation and Classification Algorithms. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, XLII-2/W3*, 339–344.

Larner J., (1972). *Signorie di Romagna. La società romagnola e l'origine delle signorie*. Bologna: Il Mulino Editore.

Malinverni, E. S., Mariano, F., Di Stefano, F., Petetta, L., Onori, F. (2019). Modelling in HBIM to document materials decay by a thematic mapping to manage the cultural heritage: the case of "Chiesa della Pietà" in Fermo. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W11,* 777-784.

Mascanzoni, L. (2003). Le grandi fasi storiche fra XII e XV secolo nello specchio dei rapporti Verucchio-Rimini. *Studi romagnoli 54(2003)*, 17-31.

Von Eles, P. (1998). *Museo Civico Archeologico*. Rimini: catalogo museale.

Pecci G., (1962). V*erucchio e la sua Rocca. Guida storico-turistica*. Verucchio: catalogo museale.

Pasini, P. G. (2013). *Itinerari Malatestiani: a Rimini e nel Riminese.* Rimini: Guaraldi Editore, 1-173.

Raco, F. Rizzi, D., Giau, G., Galvani, G., (2020). Rilievo e rappresentazione del costruito esistente per l'HBIM. Digital documentation and Historic Building Information Modeling. *Paesaggio Urbano. 3/2020*, 132-145.

Rimondini G., (1989). R*occhе, tombe e castelli, in Maricla. 8 lezioni per conoscere il fiume Marecchia e la sua valle.* Rimini: Maggioli editore.

Rodriguez-Navarro P. (ed.) (2017). Archaeological Drawing. *Disegnarecon, 10(19).*

Saygi, G., & Remondino, F. (2013). Management of Architectural Heritage Information in BIM and GIS: State-of-the-Art and Future Perspectives. *International Journal of Heritage in the Digital Era, 2(4)*, 695–713.

Spallone, R. e Piano, A. e Piano, S. (2016). B.I.M. e beni architettonici: analisi e rappresentazione multiscalare e multidimensionale di un insediamento storico. Il caso studio di Montemagno, Borgo Nuovo piemontese. *Disegnarecon 16(2016),* 1-13.

Suppa, M. (2022). *Optimisation of survey procedures and application of integrated digital tools for seismic risk mitigation of cultural heritage. The Emilia-Romagna damaged theatres.* (Doctoral dissertation). University od Ferrara, Italy.

Turchini, A. Orioli, M., Viroli, M., Novara, P. Castellari, C., (2017). *La Romagna dei castelli e delle rocche.* Cesena: Società editrice Il Ponte Vecchio.

Zerlenga, O., Corniello, L., Cirillo, V., Palmieri, A., De Cicco, A., Lento, G. P., Mqliqari, A. (2023). The architectural heritage of Berat in Albania. Photogrammetric survey, 3d laser scanner and digital modelling. In Balzani, M., Bertocci, S., Maietti, F., Rossato, L. (Eds.), *Research Innovation and Internationalisation. National and international experiences in Cultural Heritage digitisation.* (pp. 53-64). Rimini: Maggioli editore.

DOI: https://doi.org/10.20365/disegnarecon.31.2023.2