HBIM AS A TOOL FOR THE ANALYSIS AND CONSERVATION OF ARCHITECTURAL HERITAGE. CASE STUDY: THE RAME TOWER'S DIGITAL TWIN

J. García-León, P. Murrieri, P.E. Collado-Espejo

Universidad Politécnica de Cartagena, Spain - (josefina.leon, pedroe.collado, patrizia.murrieri)@upct.es

KEY WORDS: HBIM, Documentation Cultural Heritage, Digital Twin, Restoration, Operation and Maintenance.

ABSTRACT:

The Rame Tower, located in the municipality of Los Alcázares (Región of Murcia, Spain), is one of the watchtowers post coasts built in the sixteenth century in an attempt to defend the Spanish coast from attacks by Barbary pirates. Although the tower is protected monument as a BIC (Cultural Heritage Asset) is currently in a state of degradation and neglect and passively suffers the flow of time and vandalism. Like most cultural heritage assets, it is characterized by deep irregularities and heterogeneity, due both to the changes in use over the centuries and to the passage of time. In this research, a 3D survey is first realized by combining different techniques and instrumentation in order to obtain a complete cloud of points, both outside and inside. The cloud of points thus obtained serves as the basis for the realization of the HBIM model of the tower. Thanks to the points cloud you can reach a level of development (LOD) such that you can talk about digital twin of the asset. The HBIM model thus obtained will then be used for the realization of a proposal for recovery and reuse and an example of management and maintenance. The aim is to demonstrate how BIM applied to assets is useful both for its recovery and for future management and maintenance. The research also identifies which problems are found in the modeling of discontinuities typical of cultural heritage in the BIM environment and which solutions can be applied.

1. INTRODUCTION

Today the Architecture, Engineering & Construction industry (AEC) is characterized by a strong implementation of Building Information Modeling (BIM). The implementation of this methodology, however, is mostly dedicated to new buildings, for which it is less complex to reach a level of development, up to the modeling of so called as-built (LOD 500) that is a computerised digital model corresponding to the actual building.

Applying the BIM methodology to cultural heritage is more complex. The cultural heritage is characterized by strong irregularities and heterogeneity, the result of the changes of use that often these buildings undergo and, in general, the passage of time. According to the specific case it is possible to reach, in the realization of the HBIM model, a Level of Geometry (LOG) very pushed, thanks to the use of the point cloud. Even if the points cloud is used as a modeling basis, the achievement of a LOG 500 is not always guaranteed. It can happen that BIM modeling software is not yet ready to model the deep irregularities of some historical buildings (Banfi, 2016).

To reach instead an advanced Level Of Information (LOI) will be more or less possible based on the archival sources, and to eventual tests and analyses realizable on the asset.

Although the application of BIM to existing assets is still under development, there is a growing need to acquire and restore the status of historic buildings (Banfi *et al*., 2023) The aim is to use HBIM models of cultural heritage for subsequent reuse projects as well as for the management and maintenance phases.

For these reasons in this research, we wanted to approach the attempt to model a post coastal tower of the sixteenth century, proposing the goal of achieving a LOG 500.

The origin of these towers dates back to the fifteenth century when the so called "Barbary pirates" began attacks on the coasts overlooking the Mediterranean Sea, including the Spanish coast - the Valencian and the Murcian coast of the Mar Menor (figure 1) and the Balearic Islands coast - and the coasts of southern Italy.

Figure 1. Historical map of the boundaries of Murcia and Cartagena in the Mar Menor area. Anonymous 1563. Archive of the Royal Chancillería of Granada, cabin 508, section "Pesca", leg. 1659, piece 1; belongs to the "*Pleito de la ciudad de Cartagena con la Justicia de la ciudad de Murcia sobre pescar en los términos*".

The coasts of the Mar Menor became, from the early 1600s, a truly dangerous place and this prompted King Philip II to seek a solution to defend the coast and keep the people safe.

To restore security on the Spanish coast, King Felipe II commissioned the military engineer Juan Bautista Antonelli and the military architect, expert in fortifications, Vespasiano Gonzaga, to study the coast, with its weak and strategic points, and then they planned the construction of a line of defensive towers like the one that had been made in the kingdom of Valencia (Flores, 2008).

The two technicians commissioned elaborated what took the name of "Plan Antonelli". This plan would led to the construction of a large number of defensive towers, scattered along the coastal and sub-coastal zone - that is, the part of the coast that does not give directly to the Mediterranean but to the

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Mar Menor - based on carefully studied geographical positions and related to the visibility that the towers had among themselves.

The coastal protection project against pirate attacks was a unique project that saw the construction of only part of the towers designed.

From 1557, in fact, the Valencian coast began the construction of a network of towers that would have the mission of warning of the attacks on the neighboring localities and that will give origin to the so called Reservation of the Coast (Rodríguez-Navarro, 2017).

Between the 13th and 16th centuries, also Italy's southern costas, especially Calabria, Apulia, Sicily and Campania costas, were subject to frequent attacks and for this reason the construction of defensive coastal towers begins. It is assumed that on the Italian coast the towers were more than seven hundred.

The operation of the towers was this: as soon as one of the towers spotted a pirate ship, the mechanisms were activated to warn the population and the other towers with which one had eye contact, triggering a chain reaction of alerts. In particular, the warning was given through a bonfire on the roof of the tower, if it was night, or through a smoke if it was day.

In order for the signal to reach the interior territory, especially in the area of the Mar Menor, a series of towers were established, in this case to alert the population, which will be known as the post coastal towers (Pérez, 2019). The Rame Tower is one of these post coastal towers.

Despite these towers are among the most important and valuable evidence of the defensive architecture of that time, and despite most of them, including the Rame Tower, are affected by the Law of Cultural Heritage of the Región of Murcia, many have disappeared and many others are in a state of neglect and severe degradation.

The objective of this research is to obtain, starting from an accurate graphic and informational survey, the HBIM model of the Rame Tower. BIM application is prevalent mainly for new buildings, while the majority of existing buildings is not maintained, refurbished or deconstructed with BIM yet (Volk *et al.*, 2014). For this reason the use of Historic Building Information Modelling (HBIM) has become a research topic of great interest as it is able to model the state of complex historic structures throughout their life cycle (Barazzetti, 2016; Murtiyoso & Grussenmayer, 2019; Yang *et al.*, 2020a).

In order to make the Heritage o Historical Building Information Modeling (HBIM), the so called reverse engineering is applied, that is to say an inverse workflow to the traditional. Following the HBIM workflow, after the first two phases of historical-architectural documentation and geometric and constructive survey, BIM modeling and informatization of the tower has been carried out using a BIM authoring software. The aim is to obtain a level of development corresponding to the LOD 500, level that in the field of new construction is also called "as built".

The HBIM model thus obtained will allow us to realize a proposed recovery and reuse of the tower and its subsequent management and maintenance, always thanks to the application of the BIM methodology.

2. STUDY OBJECT

2.1. The Rame Tower

The Rame Tower is located in the municipality of Los Alcázares (Región of Murcia, Spain). The Tower owes its name to its location: Las Lomas del Rame or "El Ramí", a neighborhood located at the entrance of the municipality of Los

Alcázares that in the sixteenth century formed a jurisdictional lordship (figure 2).

The Rame Tower is configured, along with other towers such as the Negro (García-León *et al.*, 2019), as a post coastal tower. This because it is located in the inland area of the Mar Menor having the main function, in this case, of warning the population of fishermen and farmers who were then the main inhabitants of the area of Los Alcázares.

Figure 2. South facade and west facade of the Rame Tower. Current condition.

Some studies believe that the Rame tower dates back to the thirteenth century and that in the following sixteenth century, when the implementation of the aforementioned Plan Antonelli, became an important part of it, receiving in 1582 a complete reform and restoration (Chacon Jimenez & Benedicto Martínez, 2008). Other hypotheses see the construction of the Rame Tower directly to scope of surveillance and defense, between the sixteenth and seventeenth century. As we shall see, at this time the tower was owned by the Bienvengud family, great participant in the fight against barberish pirates.

On the ownership of the tower, since the fifteenth century, the Lomas del Rame begin to be owned by different families that would therefore also own the tower.

In 1591 it passed to the Bienvengud family, namely Diego Bienvengud Rosique (Pérez, 2019). From the 18th century the family in charge of the tower would be the Fontes. In the nineteenth century, the Fontes family carried out a comprehensive and complete reform of the Rame Tower that would adapt it to the agricultural use that at that time had.
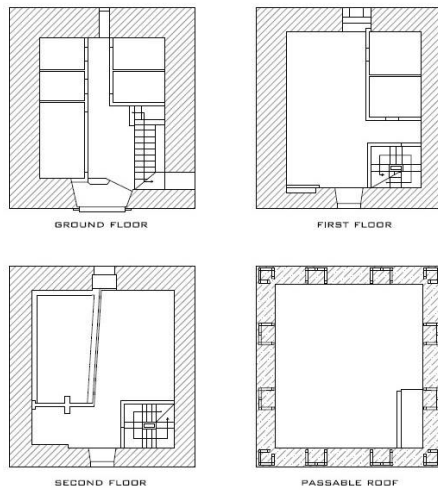
On the occasion of this reform appeared many of the elements that still conserves as the main wooden door, the stairs of the ground floor or the metal balconies (Esquivel, 2022).

In the 20th century, more precisely since 1920, the tower became the property of the Martínez Rosique family.

The graffiti found on the inside walls of the tower deserve special mention. These are graffiti dating from different periods, made between the seventeenth and twentieth centuries and concentrated especially in the first and second plant. The themes of graffiti are above all: zoomorpho and vegetable, series of accounting, epigogic theme, geometric and highlights the theme of ships. All real life topics or reflection of what the people sheltered in the tower saw in the sea, as "galleried galleon" depicted on the second floor (Rabal & Castejón, 2022).

2.2. Constructive analysis

The Rame Tower is protected as a BIC with the category of monument according to Decree 3/2006. There is a house attached to the tower and a cistern of the twentieth century also declared as BIC. The Rame tower is a square tower, composed by masonry walls and three forged two of them in the form of a barrel vault that separate its three floors (figure 3).

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Figure 3. Plans of the different floors of the Rame Tower.
The walls, made mainly of stone, have a total height exceeding 14 meters in height that go from the floor to the roof where they form a parapet that holds the battlements.

These walls also have a great thickness, specifically of 1.5 m that decreasing the thickness with height having in the second floor 1.10 m. The loads are collected in each of the floors by the barrel vaults that transmit them at their ends through the length of the walls that in turn take them to the foundation that is responsible for distributing them on the ground.
As for typology and materials highlights the ribbed vault of the second floor made of solid brick.
Another important constructive element is the staircase that is formed by two main bodies: the first of them located on the ground floor and formed mainly by a wooden structure and the second body that composes the rest of the staircase and consists of a factory staircase.
Please note that in their original layout, the towers did not have stairs on the ground floor for safety reasons. This is why the stairs that can be seen today, which allow the connection between the ground floor and the first floor, certainly date back, as can be seen from the materials used, to a later period, to that of the rest of the tower.

2.3. State of conservation

Despite, as already specified, the Rame Tower is a protected monument as a BIC (Cultural Heritage Asset) according to the first transitory provision of the Law 4/2007 of Cultural Heritage of the Región de Murcia (BORM, 2007), is currently in a strong state of neglect and degradation (figure 2).
The two most important conservation problems are the building's own pathologies and vandalism.
More specifically, the outside of the tower is affected by detachment and change of color of the facade cladding coupled with the appearance of rust that is seen in the metal balconies of the South facade.
On the inside, instead, moisture by condensation has produced the appearance of mold by many of its walls and ceilings and lichen in the elements of the flat roof. Always internally it is easy to detect the presence of insects such as the wasp and its nests throughout the tower but especially of the common woodworm, whose effect is especially noticeable in the wooden structure that holds the staircase on the ground floor.

3. METHODOLOGY

The workflow described below has been applied with the purpose, as previously anticipated, of obtaining the digital twin of the Rame tower. The HBIM model, with LOD 500, thus obtained, will then be used to propose a hypothesis of intervention and management and maintenance. It should also be added that the HBIM model of the building will be upgradeable and useful for all stages of the asset's life cycle.

3.1. Survey phase

The relief of the Rame tower was divided into two phases characterized by the use of different techniques and instruments. In both cases it was data acquisition techniques that generate 3D points cloud useful to describe the surface of a real-world object or a scene (Kyriakaki-Grammatikaki *et al.*, 2022).
The external survey of the tower was performed with the Leica Nova MS50 multi-station. Thanks to 5 stations, (figure 4) plus a specific scan made by point "A" for the shield above the access door of the South facade, a cloud of 13,002,708 points was obtained which have been dumped in the Infinity software.
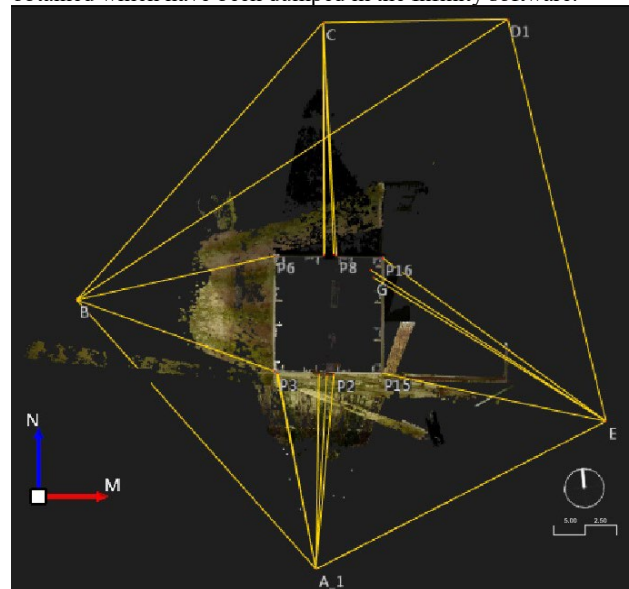
Figure 4. Top view of the station points and control points used in survey of the Rame Tower.

Also, 13 natural control points were taken from the different stations and distributed throughout the surface of the model, to perform the verification of the accuracy in the final model obtained. The control points measured by topography *in situ* in the tower were compared with their equivalents in the generated model. The different between them show that they never exceed 3mm in their 3D quadratic component.
The use of multi-station instead did not seem the best solution for the survey of the interior. The internal space of the tower has relatively small dimensions and sees the presence of dividing walls that divide the interior space into even smaller rooms for the relief of which has been used the application "3D scanner App" version 2.0.13 (1) installed on a 12.5-inch iPad pro (figure 5). The workflow has provided for the division of the relief into 7 stations, for as many clouds of points, corresponding to as many areas of the tower. A relief was then made for each of the three levels of the tower, one for each staircase connecting the various levels and finally one for the outdoor terrace. Each survey generated a cloud of points, which can be used separately on the BIM authoring software but aligned with the others. In this way it is possible to have an overview of the

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

interior but at the same time "turn on" only the cloud of points useful according to the modeling phase in which you are.

Figure 5. Cloud of 1.445.466 points of the staircase of the ground floor of the Rame tower, obtained with 3D scanner app installed on iPad Pro.

3.2. Scan to BIM

The second phase of the investigation workflow consists in the creation of the HBIM (Historical/Heritage BIM) model of the tower from the point clouds obtained from the previous 3D survey phase.

BIM modeling from the point cloud allows creation of parametric objects (Murphy *et al*., 2013; Macher *et al*., 2017; Capone & Lanzara, 2019) but is not an automatic process. The point cloud was loaded into the BIM authoring software and served as the basis for BIM modeling.

The model was therefore created from the geometric and spatial information contained in the point cloud and was then enriched with all other complementary information.

This information - materials, stratigraphies, years of construction - has been duly incorporated into the model and properly structured, so that the end result of this BIM modeling phase is useful for subsequent recovery and management applications.

First, therefore, the point clouds were uploaded to usBIM.poincloud and then imported to the BIM authoring software (Edificius by ACCA Software S.p.a. in the version usBIM(d)) only the portions really useful for the tower modeling.

The next step was to define the levels and dimensions of the different floors of the tower to place the point cloud and align it to our reference system.

As mentioned in paragraph 3.1. the 3D relief of the tower was divided into two phases, one for the outside and another for the inside of the tower. To join the point clouds generated by these two phases of the survey, two paths have been tried: the first with the use of the 3DReshaper software and the second directly using the BIM authoring software.

Evaluating the results obtained with a first attempt, it was decided to proceed with the BIM modeling software. From here you can load as many point clouds you need in different levels, align them with each other but at the same time manage them separately. We proceed by inserting, on the pint clouds, all the horizontal and vertical sections that we need to extrapolate the geometric information necessary for modelling (figure 6).

Figure 6. Import and align point clouds on BIM authoring software, manage quotas and levels and insert vertical and horizontal sections.

As anticipated, the BIM modeling process from point cloud is not automatic. The cloud acts as a geometric basis for the modeling that takes place through the classic commands of the BIM design software. Simultaneous visualization of the model and the point cloud allows you to achieve a high level of detail and reproduce as accurately as possible the irregularities of the tower. Figure 8, for example, shows the modelling of the balcony of the second floor and its metal supports. In an ideal model the supports would be perpendicular to the wall (red lines in the figure). From the points cloud, however, it is clear that each support has a degree of rotation different from the facade (figure 7).
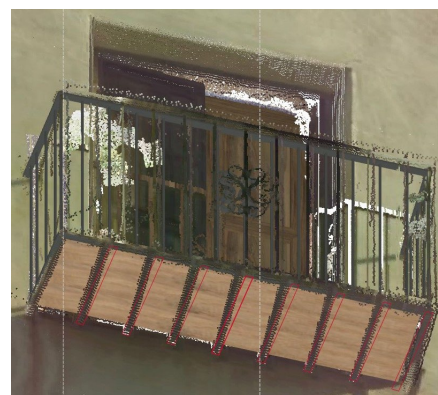
Figure 7. Example of irregularities in the balcony of the second floor and its metal supports, modelled by the point cloud. The red lines indicate the inclination that the metal supports would have in an ideal model.

Particular attention was paid during the modelling phase to the building elements "external walls" and "stairs". The difficulties encountered are due the different thicknesses and to the inclination towards the inside of the perimeter walls, different from wall to wall, and the peculiarities and heterogeneity of the stairs. The stairs are formed by two main parts, the first of them located on the ground floor and formed mainly by a wooden structure and the second part that composes the rest of the staircase and consists of a factory staircase. The modelling of such a characteristic constructive element, with ramps all different from each other, has been carried out, always having

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

as base the points cloud, modelling first the ramps and the landings of the stair in the architectural menu and then drawing the vaults in support in the specific editor (figure 8).
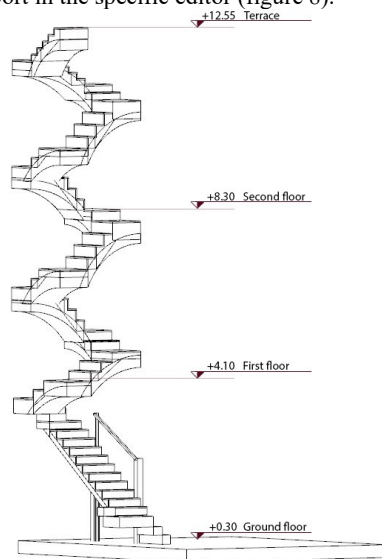
Figure 8. Stairs modeled from point cloud.

Another characteristic element is the sail vault of the second floor. In fact, the command inside the software allows you to model sail vault on a square base. However, from the points cloud it was possible to appreciate that the vault detected in the tower is characterized by an irregular plan. Therefore, once again, the irregularities of the building under study, typical of such an ancient property, required the study of alternative modelling techniques always respecting the properties related to IFC classes. In detail, for the modeling of this time we have first of all identified with precision the subtended area of the vault and then a dome was built to cover this area. The next step was the elimination of the sections of caps outside the identified area, using the vertical cuts in the appropriate vaults editor. The horizontal cuts were then used to define the correct portion of the roof supports (figure 9).


Figure 9. Sail vault of the Rame tower. Its irregular plan required a specific modelling strategy from a dome.

The elevations of the tower are now characterized by bricks that frame the entrance door and that crown the tower. Given the particular arrangement of these bricks, especially in the crowning of the parapet, the modelling and subsequent

inclination was made individually for each brick. The aim is always to reproduce as accurately as possible, even such peculiar constructive and decorative elements.

Just above the entrance door we find one of the most representative elements of the South facade of the tower: a molded shield representing the Bienvengud family, owner of the tower since 1591. As previously mentioned, a special scan with a greater level of detail was carried out for this element. The scan was then used to obtain a 3D model. This model has been added to the BIM authoring software as a 3D object with obj extension (figure 10).
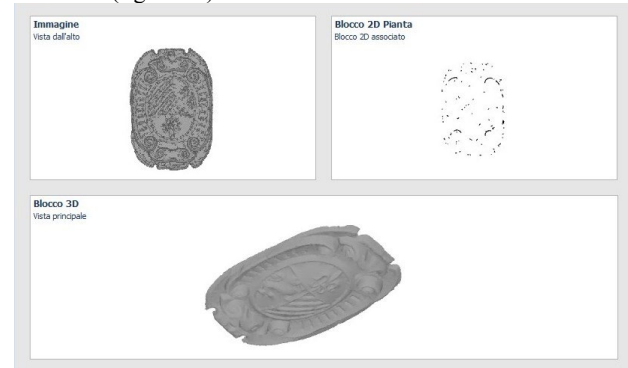
Figure 10. Insertion of the 3D model of the shield in the BIM software.

In paragraph 2.1. has been evidenced as the tower object of study has endured changes of property and use that have been manifested through the constructions of new elements over the centuries. This aspect has been made known in the BIM authoring software by characterizing the IFC group of each element. The name of the IFC group was given "year built" and the description was added 16th century or 19th century according to the specific entity.

This is very important because the HBIM of a building is useful for all future phases of its life cycle. It means that when you share the model with other professionals involved, they will have access to all the information implemented including the year of construction of each entity, useful information when planning proposals for restoration and/ or reuse.

Once the modelling is completed, it is obtained a model that reproduces with the greatest precision and detail possible, the current state of the tower (figures 11 and figures 12).

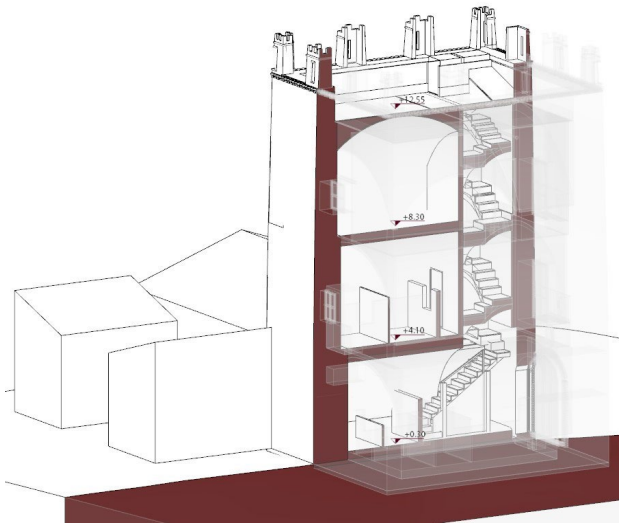**Figure 11a**. Axonometric split of the model, East-West direction.

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Figure 11b. Axonometric split of the model, North-South direction.

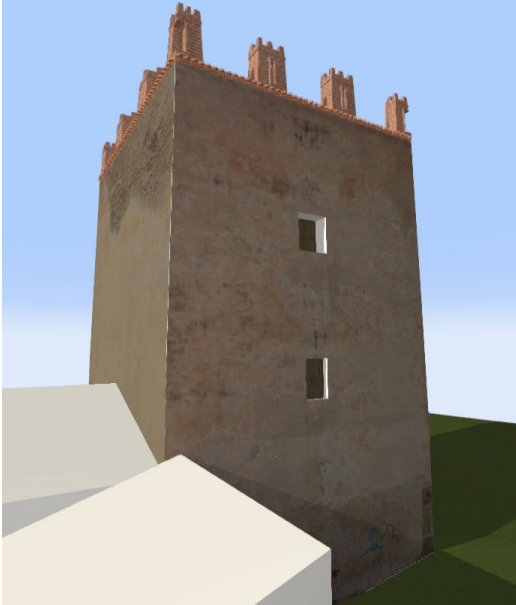**Figure 12a**. 3D view of the Rame Tower HBIM, South view.

Figure 12b. 3D view of the Rame Tower HBIM, North view.

3.3. Proposal for renovation and reuse

Has been made a proposal for intervention and reuse of the property. It is fundamental to emphasize that there is no preservation of an asset of the cultural heritage if there isn't an adequate use of it. Foresee a use of a historical asset, in fact, involves not only an initial recovery project but also a subsequent management and maintenance plan.

In the BIM methodology it is possible to realize a project group characterized by the simultaneous and comparative presence of the current situation, in yellow, and project status in red (figure 13).

In the project state, it is possible to proceed with the design of the intervention proposal using the usual modeling entities and other tools to "demolish" what of the current status you want to delete and eventually restore them.
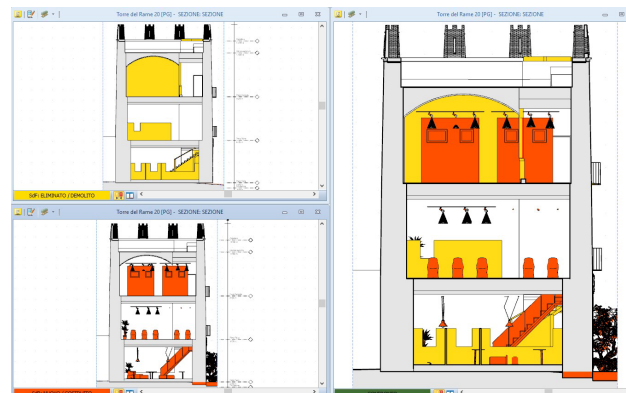

Figure 13. Simultaneous tables of current status, project status and comparison.

Therefore, once the integrity of the tower faces has been restored by intervening in a specific way according to the pathology, we move on to the redesign of the interior spaces.

The project proposal in this phase of research is to make the Rame tower a cultural and museum center. The museum, on the second floor of the tower, will host temporary exhibitions with a view to foment and dissemination of the activity of local artists. The cultural part instead is designed to insert a dynamic aspect and keep the tower alive by ensuring the maintenance. The ground floor and the first floor of the tower will be dedicated to this cultural aspect. Here it will be possible to diferent cultural activities, so as to reach a wider and varied audience, such as: book presentations, food and wine events, desgustations, workshops on local arts and crafts, etc.

In the interiors, the graffiti inside the tower will be protected and exposed in total safety while the partitions created over time to adapt the building for agricultural use have been eliminated, walls that both on the first and second floor also block the opening and the correct use of the windows. In this phase, the IFC group characterized in the modeling phase is very useful. This information in fact reminds us of the year of construction of each entity and guides us in choosing what to demolish and what not, respecting the originality of the property BIC.

Another element that is considered necessary to demolish and replace is the wooden staircase of the ground floor. Currently, the wood is extremely deteriorated and the staircase is unsafe. It is therefore considered useful to build a new wooden staircase.

Regarding the colour of the outer walls of the tower, it was decided to replace a white colour. This choice is dictated by the fact that being a tower intended for surveillance and defense, it is most likely that the original plaster, even before the pink

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

plaster emerged in the 19th century reform, was white. Also externally, to break down architectural barriers and allow access to the tower for people with reduced mobility, an external access ramp has been set up.

The tower is surrounded by a garden also in a deep state of neglect. To ensure that the tower recovers a use and maintenance, it is essential that it is integrated with the communal garden, removing the current fence and incorporating furniture and garden equipment (figure 14).

Figure 14. Rendered axonometric of the proposal for intervention and reuse.

### 3.4.Proposal of operation and maintenance

The application of BIM to the phase of Operation&Maintenance (O&M) makes available for each component the necessary information to plan an intervention. Thanks to BIM the information is then shared with all professionals involved in the project, are upgradable and notifiable in real time (Bruno *et al*., 2018). This allows to optimize this phase by reducing costs and time (Khajavi *et al*., 2019). It must be underlined that higher the level of development achieved more the model will be useful for the subsequent stages of the life cycle of the asset. The realization of the digital twin is very important to realize predictive maintenance (Zhong *et al*., 2023).

In this research we realized an example of a maintenance plan through the BIM architectural modeling software that interacts with the software for the preparation of the maintenance plan (Mantus by ACCA Software S.p.a.).

From the layers or from the 3D view the objects to which to associate the maintainable elements have been selected and then the integration with the appropriate software has been opened.

It has been hypothesized a maintenance plan that regards, among other things: external and internal walls and plaster as their element, balconies of which the metal railings and the wooden part as associated elements, wooden doors and windows, roofing.

Opening then the integration with the maintenance software has been perfected maintenance plan. Regarding for example the external walls, we know that they are currently subject to loss of material, change of color and stains and graffiti, so we report such pathologies as anomalies and we choose to check their reappearance every six months, by selecting as a precaution also the control of other pathologies potentially detectable (figure 15).
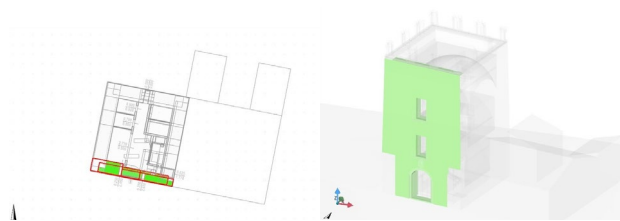
Figure 15. Selection of walls for which a semi-annual control of degradation pathologies has been set.

The same approach and procedure was followed for the various elements of the model, elaborating a maintenance plan hypothesis for the Rame Tower.

4. CONCLUSIONS

The result of this research was the realization of the digital twin of the Rame tower which has allowed to incorporate both the restoration and the maintenance proposals of this cultural heritage, making possible the use of this digitization throughout the life cycle of the tower.

The tower object of study is, as seen so far, characterized by many irregularities typical of such ancient buildings, in which the materials and construction techniques of the time, the changes applied over time and the degradation of recent years, add up resulting in a strong heterogeneity.

The main difficulty that is found in the modelling of buildings of the existing patrimony, consists in the faithful reproduction of such heterogeneity. The difficulty increases when the model you want to realize is a BIM, especially if of LOD 500. In a BIM model in fact each element must be modeled considering the IFC class, therefore the properties that each element inherits from the parent class to which it belongs and the properties instead editable on the single instance.

The BIM model of the Rame tower was made from the points cloud and this has an important advantage, especially when the purpose is to realize the digital twin of the building: to be able to achieve a very high degree of precision. In fact, realizing the HBIM model from the point cloud, some differences were detected compared to the 2D survey, many small irregularities in the various construction elements were appreciated and it was possible to appreciate with precision thickness and geometry of peculiar elements such as the stairs and the sail vault of the second floor.

When the construction elements are particularly peculiar and irregular, the modeling involves the identification of particular strategies, such as those used for modeling the stairs and the sail vault of the Rame Tower.

The correct modelling of the walls with thicknesses and inclinations so variable to the variation of the section was possible only from the usBIM(c) software version onwards.

Additionally, with the BIM methodology you can parametrically define the areas of degradation and then make them object informative, upgradeable and editable. However, the existing assets are so heterogeneous that the standard application of the commands is not always possible. In this specific case, for example, the attempt to identify and computerise areas of degradation failed. Once out of the degradation editor, the identified areas were jagged, lost the contour previously identified and then any use for a future restoration. The cause of such a display error may lie in the deep irregularity and the difference in thickness of the exterior walls characterized by degradation. This heterogeneity may not yet be compatible with BIM software.

There was also an impediment to rendering the model in the actual state. The orthophotos positioned to characterize the facades of the tower are, in the rendering phase, offset and

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

decomposed without an apparent criterion. This problem will be solved in the next versions of the BIM software. They will have to perfect the modelling techniques for such irregular elements as those that characterise cultural heritage buildings.

The management of the tower throughout the lifecycle will be carried out in a collaborative environment and in real time thanks to the digital twin presented.

REFERENCES

Banfi, F. (2016). Building information modelling – A novel parametric modeling approach based on 3D surveys of historic architecture. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 10058 LNCS, 116–127. https://doi.org/10.1007/978-3-319-48496-9_10

Banfi, F., Roascio, S., Mandelli, A., & Stanga, C. (2023). Narrating Ancient Roman Heritage through Drawings and Digital Architectural Representation: From Historical Archives, UAV and LIDAR to Virtual-Visual Storytelling and HBIM Projects. Drones, 7(1). https://doi.org/10.3390/drones7010051

Barazzetti, L., 2016. Parametric as-built model generation of complex shapes from point clouds. *Advanced Engineering Informatics*, *30*(3), pp.298-311.

Bruno, S., De Fino, M., & Fatiguso, F., (2018). Historic Building Information Modelling: performance assessment for diagnosis-aided information modelling and management. *Automation in Construction*, 86, pp. 256-276. https://doi.org/10.1016/j.autcon.2017.11.009.

Capone, M., & Lanzana, E., 2019. Scan-to-BIM vs 3D ideal model HBIM: parametric tools to study domes geometry. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42-2/W9.

Chacon Jimenez, F., & Benedicto Martínez, J. F. (2008). Historia de Los Alcázares. Volumen I. Los Alcázares en el contexto de la formación de la comarca del Mar Menor. Editum Universidad de Murcia. Murcia.

Esquivel Izquierdo, R., *Torre del Rame (s. XVI) en Los Alcázares: análisis integral propuestas para su restauración, conservación y puesta en valor* [final project]. Cartagena: Universidad Politécnica de Cartagena, 2022.

Flores Gutiérrez, M. (2008). *Amenaza pirata en el Reino de Murcia* (documental). Fundación Integra, Región de Murcia y Unión Europea.

García-León, J., Collado Espejo, P. E., & Jiménez González, F. J. (2019). Negro Tower: documentation, conservation, and restoration. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2/W15), 489–496. https://doi.org/10.5194/isprs-archives-XLII-2-W15-489-2019.

Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmstrom, J. (2019). Digital Twin: Vision, benefits, boundaries, and creation for buildings. IEEE Access, 7, 147406–147419. ttps://doi.org/10.1109/ACCESS.2019.2946515

Kyriakaki-Grammatikaki, S., Stathopoulou, E. K., Grilli, E., Remondino, F., & Georgopoulos, A. (2022). Geometric primitive extraction from semantically enriched point clouds. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *46*(2/W1-2022), 291–298. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-291-2022.

Macher, H, Landes, T., & Grussenmeyer, P., 2017. From point clouds to building information models: 3D semi-automatic reconstruction of indoors of existing buildings. *Appl. Sci.,* 7, 1030.

Murphy, M., McGovern, E., & Pavia, S., 2013. Historic Building Information Modelling -Adding intelligence to laser and image based surveys Elsevier. *ISPRS J. of Photogrammetry and Remote Sensing*, 76, pp. 89-102.

Murtiyoso, A. & Grussenmeyer, P., 2019. Point cloud segmentation and semantic annotation aided by GIS data for heritage complexes. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 42, pp. 523-528.

Pérez Lizán, B. (2019). "Historia y Estado de Conservación de las torres Vigías y Defensivas del litoral de Murcia". En revista *IMAFRONTE Nº 26,* Universidad de Murcia; pp. 183-220.

Rabal Saura, G., & Castejón Porcel, G. (2022). Los Grafitos de la Torre del Rame. Imágenes para otra historia del Mar Menor y su comarca. Asociación Los Alcázares Eco-Cultural. Los Alcázares.

Rodríguez-Navarro, P., "TOVIVA Project: una experiencia en torno al proyecto de defensa de la costa valenciana entre los siglos XVI al XVII" in Defensive Architecture of the Mediterranean. XV to XVIII Centuries, Vol 6, Publicacions Universitat d'Alacant, Alicante, Spain, 2017, pp. 345-352.

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings - Literature review and future needs. In Automation in Construction (Vol. 38, pp. 109–127). https://doi.org/10.1016/j.autcon.2013.10.023.

Yang, L., Cheng, J.C. & Wang, Q., 2020. Semi-automated generation of parametric BIM for steel structures based on terrestrial laser scanning data. *Automation in Construction*, *112*, p.103037.

Yang, X., Grussenmeyer, P., Koehl, M., Macher, H., Murtiyoso, A. & Landes, T., 2020. Review of built heritage modelling: Integration of HBIM and other information techniques. *Journal of Cultural Heritage*.

Zhong, D., Xia, Z., Zhu, Y., & Duan, J. (2023). Overview of predictive maintenance based on digital twin technology. Heliyon, e14534. https://doi.org/10.1016/j.heliyon.2023.e14534