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Data sharing and interoperability in HBIM applied to the Rame Tower

Together with the gradual spread of BIM in the AECO industry, the concept of open BIM began to take root. Semantically HBIM has demonstrated its ability to dialogue with a wide range of stakeholders though multiple visualization and representation tools.
But to be able to apply them from the perspective of interoperability among all the professionals, it is necessary to work with standards. For this reason, there has been a growing interest in HBIM, but the process requires specialized standards, today there are only a few recommendations.
The bSDD allows linking between all the content inside the database. It provides a standardised workflow to guarantee data quality and information consistency. Projects must be based on openBIM methodologies, using only open, non-proprietary standards and formats, to guarantee an interoperable and collaborative workflow.
It has been applied to the Rame Tower, a pre-16th century cultural heritage site, and a characterisation has been achieved based on an international standard language that is interoperable, allowing all stakeholders to share and exchange information about the objects and their properties, increasing the future possibilities for coordination and collaboration throughout the life cycle of the asset.
The Digital Twin obtained through this HBIM modelling process is fully dynamic, sharable, and usable in all phases of the asset's life cycle, and the characterisation and codification based on the interrelation between IFC and bSDD makes the project fully open and sharable.
In addition the incorporation of blockchain technology together with HBIM helps to improve aspects such as: authorship and traceability of processes, metadata registration and quality in the creation phases among others.

Keywords:
bSDD; Scan to BIM; Open HBIM; Accessibility; Blockchain

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1. INTRODUCTION

The development of HBIM is mainly focused on three issues. The first is to adapt the BIM methodology to the specific characteristics of historic architecture (Banfi,2016). The second is improving the geometric accuracy, workflow of data capture and surface model acquisition (Murphy et al., 2009), (Dore et al., 2015). The third is the enrichment of model-related data. Semantically HBIM has demonstrated its ability to dialogue with a wide range of stakeholders though multiple visualization and representation tools (Santoni et al., 2021).
But in order to be able to apply them from the perspective of interoperability among all the professionals, it is necessary to work with standards and make the BIM openBIM. For this reason, there has been a growing interest in HBIM, although there are only a few international recommendations and each country is using them in a different way (Argasinski & Kuroczynski, 2023).
Among the various standards developed by buildingSMART (bSI), the international body committed to the creation and dissemination of common, open data standards, two are particularly useful: the Industry Foundation Classes (IFC) standard and the Building Smart Data Dictionary (bSDD) standard.
The IFC is an open international standard (ISO 16739-1), intended to be vendor-independent or vendor-agnostic, and usable across a wide range of hardware devices and software platforms. The IFC is a standardised data model that encodes identity and semantics, characteristics or attributes and relationships. And it can do so from objects, abstract concepts, processes or people.
Although the IFC standard is the most widespread in the AECO sector and enables interoperability across disciplines, it does not take into account many needs related to the peculiarities of existing assets. This gap forces operators in the sector to customise the content of the information, opening up a major problem of sharing and collaboration, especially when it comes to pathologies or loss of information.
The bSI has developed another standard, the bSDD, which is a library of object concepts and related attributes based on the IFD standard (ISO 12006-3). It is used to identify objects in the built environment and their specific properties independently of the language, associating to existing standards specific and design rules in relation to the case study. Thanks to this tool, AECO operators can overcome the limits of linguistic or software subjectivity, as objects and properties are uniquely and objectively recognised thanks to a semantic mapping that connects the signifier with the signified.
The bSDD provides a standardised workflow to guarantee data quality and information consistency (Mêda et al., 2021). For bSDD end-users to verify the validity and conformity of data they can work on their own BIM freel, implementing the necessary information and without binding other users (Scandurra & di Luggo, 2023).
Finally, blockchain technology is a type of decentralised digital record that is used to store data securely, transparently, and permanently. In essence, it is a database that is organised through linked records. The key aspects of this technology are several:
1. Decentralisation: the information does not rely on a single intermediary or authority but is operated in a network of multiple independent computers that validate and record the data, reducing the risks of failure or manipulation.
2. Security: this is achieved through cryptographic techniques that link blocks of information, preventing and detecting tampering attempts.
3. Transparency: access to records is public and verifiable.
4. Contracts can be registered that define actions between different actors, and even executed autonomously when certain conditions are met.
If blockchain is applied in data exchange and interoperability in HBIM with standards, the following aspects would be improved:
- When multiple parties are involved, automatic smart contracts can be created that delineate the obligations and responsibilities of the various stages (Cheng, 2019).
- Record geometric quality analysis (Capone & Lanzana, 2019) and adequacy of property descriptors (Alexiev et al., 2023).
- Enable government authorities to track operations carried out on cultural heritage (Elghaish et al., 2023).

When researching architectural heritage, one works with material, architectural and structural characteristics, and peculiarities of historic buildings, and it is essential to identify or elaborate a standard communication code. This standard should allow an international understanding of the content of the information and, at the same time, enable all operators in the sector to collaborate as "openly" as possible and thus communicate the complexity of the specific case without misunderstandings or loss of content. To this end, one of the first steps is to identify the pathologies that affect our building, so that once they are known and communicated, we can apply the rest of the phases, such as the intervention and maintenance of the heritage to which it is applied.
The main objective is to achieve a characterisation based on an international language that everyone can use to characterise a HBIM of the Rame Tower, a defensive culture heritage tower. Enriching the digital twin with information in international and standard language following the IFC and bSDD formats, in full openBIM perspective.

Figure 1. Rame Tower, house attached to the tower and the cistern are declared BIC. https://www.turismoregiondemurcia.es/es/lugar_de_interes/torre-del-rame-6880/

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2. STUDY OBJECT

The Rame Tower is located in the municipality of Los Alcázares (Region of Murcia, Spain) and is protected as an Asset of Cultural Interest (BIC) under Decree 3/2006. The house attached to the tower and the cistern of the twentieth century are also declared BIC (Fig. 1).
This tower is located on the coast of the Mar Menor. The Mar Menor is a hypersaline coastal lagoon, with a surface area of 135 km2. It is located on the southwestern Mediterranean coastline with a mean depth of 3.6 m and a maximum depth of 6 m (Fig. 2). It has a sandy bar 22 km long and 100–900 m wide called La Manga, acts as a barrier between the lagoon and the Mediterranean Sea. There are two main islands and three other smaller islands, one of which is artificially connected to La Manga. The lagoon has a regional protection according to the law3/2020, it is considered a wetland of international importance and a law that gives legal personality to the Mar Menor lagoon and its basin law 19/2022.

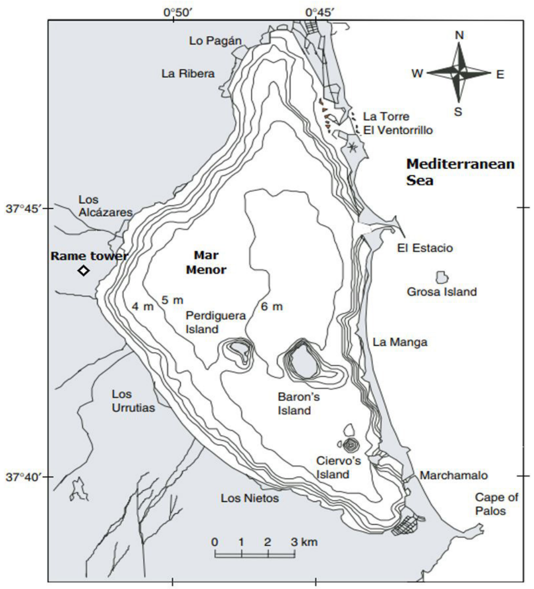

Figure 2. Bathymetry of the Mar Menor and the position of the tower object of study, Rame Tower. (Pérez-Ruzafa et al., 2005).

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 interior of the Mar Menor having the main function of warning the population of fishermen and farmers who were then the main inhabitants of the area of Mar Menor.
During XVI century, the Mediterranean had become a natural frontier between the Spanish and Turkish empires causing Spanish coasts to suffer permanent attacks from Turkish-Berber corsairs from North Africa (Velasco, 2017). To deal with these attacks, King Philip II initiated a project consisting of the construction of an extensive network of watchtowers and defence towers along the Mediterranean coastline, especially along the most besieged coasts. This network of coastal towers, which were built between the 16th and 17th centuries, had a dual mission: to watch over and defend the coastal waters, and to serve as a warning to the inhabitants of the area.
The design of the network of towers was entrusted to the Italian military engineer Giovanni Battista Antonelli and Vespasiano Gonzaga. After a first phase of field reconnaissance and the planning of the number of defensive towers required, the best location for these constructions was determined in order to better watch over and defend the entire Spanish Mediterranean coastline, including the islands. All of this was part of a project called 'Plan Antonelli'.
The fundamental characteristic of this defense network was the visibility and coordination among the different towers (Fig.3). The success or failure of the Berber incursions depended, to a large extent, on the rapidity of the warning between the coastal and inland towers. Therefore, the network of watchtowers and seashore defense would be based on three types of constructions. A first type would be the watchtowers directly on the coastline, which formed the first line of defense against enemy incursions. A second group was the fortress towers, located inland, but in direct visual contact with the watch towers on the coastline. These constructions were used as refuges and safe houses for the population and agricultural settlements that were dispersed in small areas, far from the protection of the most important castles or fortresses. Therefore, there was an internal network of constructions permitting the inhabitants of small settlements to shelter and defend themselves from hostile forces. The third group were the interior towers, far from the coast, which would provide surveillance and protection to more important populations, which could also be attacked by the North African corsairs (Gómez et al., 2003). Figure 3 shows the visibility between the different towers in the Mar Menor. It can be seen that there is complete visibility between the towers, and in the shadow cast by the island outside the Mar Menor there is a shadow (Fig.3) which was used by the pirates to rest and water to prepare for attacks.
Unfortunately, this important historical architectural and cultural heritage of the Mediterranean

Figure 3. Image from the visibility study among coastal towers and fortress towers with the Negro Tower as the origin (García-León et al., 2019).

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coast has lost one of its main characteristics: unity. Many of the towers have disappeared and several of them have been abandoned. Of the seven towers shown in Figure 3, only the Rame Tower and the Negro Tower remain, the latter being in imminent danger of collapse.

3. METHOLOLOGY

The informative characterisation takes into account the degradation phenomena previously mapped, with the aim of analyse the material degradation and lesions on the architectural surfaces of the tower. Thanks to the BIM the pathologies identified are parametric, computerised and dynamic objects. And finally, classify the degradation using openBIM tools, associating the IFC file with the bSDD to allow all interested parties to share and exchange information on the objects and their properties. The pathologies identified will be coded and characterized by an open and international language based on bSDD to increase accessibility and interoperability. The methodology was divided into different phases (Fig. 4).

3.1. Documentation

In the 16th century, the Rame tower already appears on maps (Fig. 5). Some studies believe that the Rame tower dates back to the 13th century and that in the 16th century, it became an important part of the Antonelli Plan, receiving in 1582 a complete reform and restoration (Chacón & Benedicto, 2008). Other hypotheses contemplate the construction of the Rame Tower directly to the area of surveillance between the sixteenth and seventeenth centuries. The walls of the tower preserve graffiti made in these centuries showing Berber ships that could be seen in the sea from the tower itself (Rabal & Castejón, 2022). As we will see, at this time the tower was owned by the Bienvengud family, great participant in the fight against the Barbary pirates and tower owners since 1591. From the 18th century the family in charge of the tower would be the Fontes. In the 19th century, the Fontes family carried out a comprehensive and complete reform of the Rame Tower that would adapt it to the agricultural use that existed at that time. On the occasion of this reform, appeared in the Tower many of the elements that still conserves as the main wooden door, the stairs of the ground floor or the metal balconies. In the 20th century, more precisely since 1920, the tower became the property of the Martínez Rosique family (Pérez, 2007).

The Rame tower is a square tower, composed of masonry walls with three heights, two floors and a walkable roof. The structural system consists of barrel vaults on the ground and first floor and a partition vault on the second floor that transmit the loads to the load walls of the enclosure to the foundation. The external walls have a small inclination towards the interior and have a great thickness variable according to the height, specifically of 1.5 m on the ground floor up to 1.10 m on the second floor. In terms of typology and materials, the partition vault on the second floor is made of

Figure 5. 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".

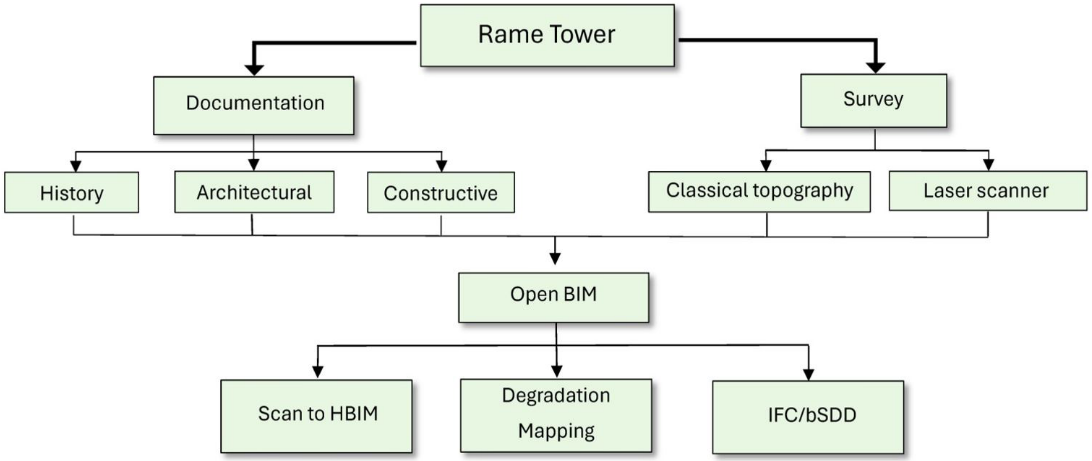

Figure 4. Workflow diagram..

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Figure 6. Data capture of the Rame tower.

Control point	Variation in X (mm)	Variation in Y (mm)	Variation in Z (mm)
P1	0,1	2,8	1,1
P2	0,3	2,8	1,1
P3	0,5	2,3	1,9
P4	0,6	2,9	0,6
P5	0,2	3,0	0,5
P6	2,4	0,5	1,8
P7	2,3	0,8	1,8
P8	0,2	2,7	1,4
P9	0,1	2,7	1,4
P10	0,2	2,9	0,8
P11	0,1	2,9	0,8
P12	2,4	0,5	1,8
P13	2,1	1,6	1,6

Figure 7. Calculation of model accuracy using control points.

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.

3.2 Survey

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 (Fig.6). Thanks to 5 stations, 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
Also, thirteen 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 (Fig.7).
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. The workflow has provided for the division of the relief into seven 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

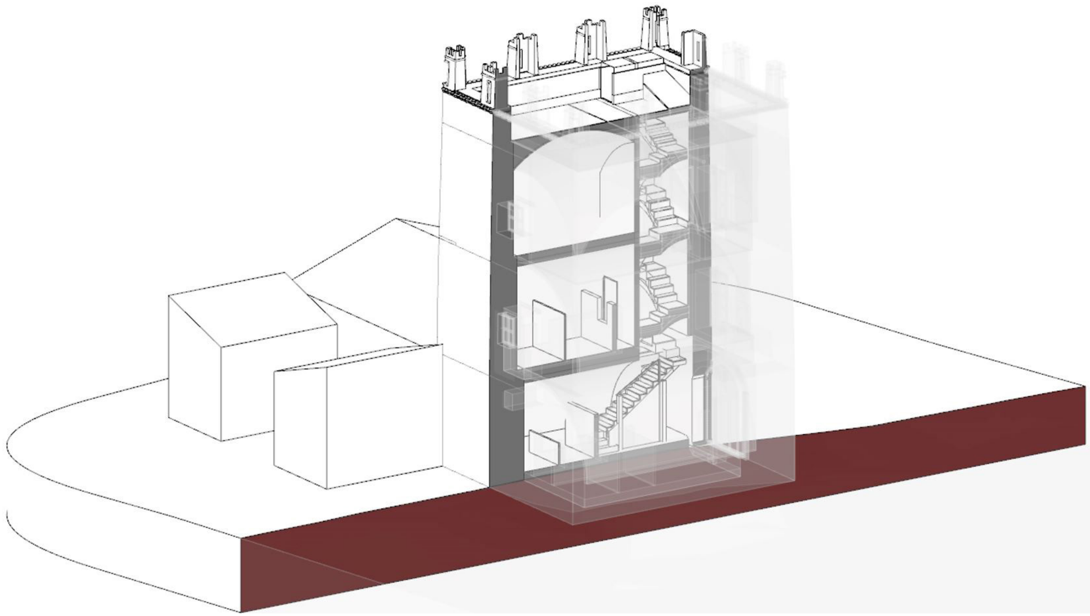

Figure 8. Surface model acquisition of the Rame tower with Edificius by ACCA Software S.p.a.

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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 interior but at the same time "turn on" only the cloud of points useful according to the modeling phase in which you are (Fig. 8).

3.3. Open BIM

OpenBIM does not mean software or a specific application, but an approach to the design, construction and management of buildings that is based on interoperability and data sharing between different software.
OpenBIM is a collaborative process that is vendor-neutral. It is based on the interoperability between the various specialist disciplines involved in the life cycle of a asset and has the objective of overcoming any technological and communication barriers that may hinder the coordination and collaboration between professionals AECO sector.
OpenBIM helps connect people, processes and data to achieve asset delivery, operation and maintenance goals and provides as the final result an accessible digital twin which provides the core foundation to a long-term data strategy for built assets.
This collaborative process, precisely because of the principle of interoperability, is based on the use of open and standard formats, which extend and amplify the potential of BIM by creating common alignment and language. Among the standard formats available today we find just: IFC and bSDD.

3.3.1. Scan to HBIM

The second phase of the workflow consisted of HBIM (Historical/Heritage BIM) modelling of the tower from the point clouds obtained from the 3D survey. BIM modeling from the point cloud allows the creation of parametric objects (Capone & Lanzara, 2019) but is not an automatic process.

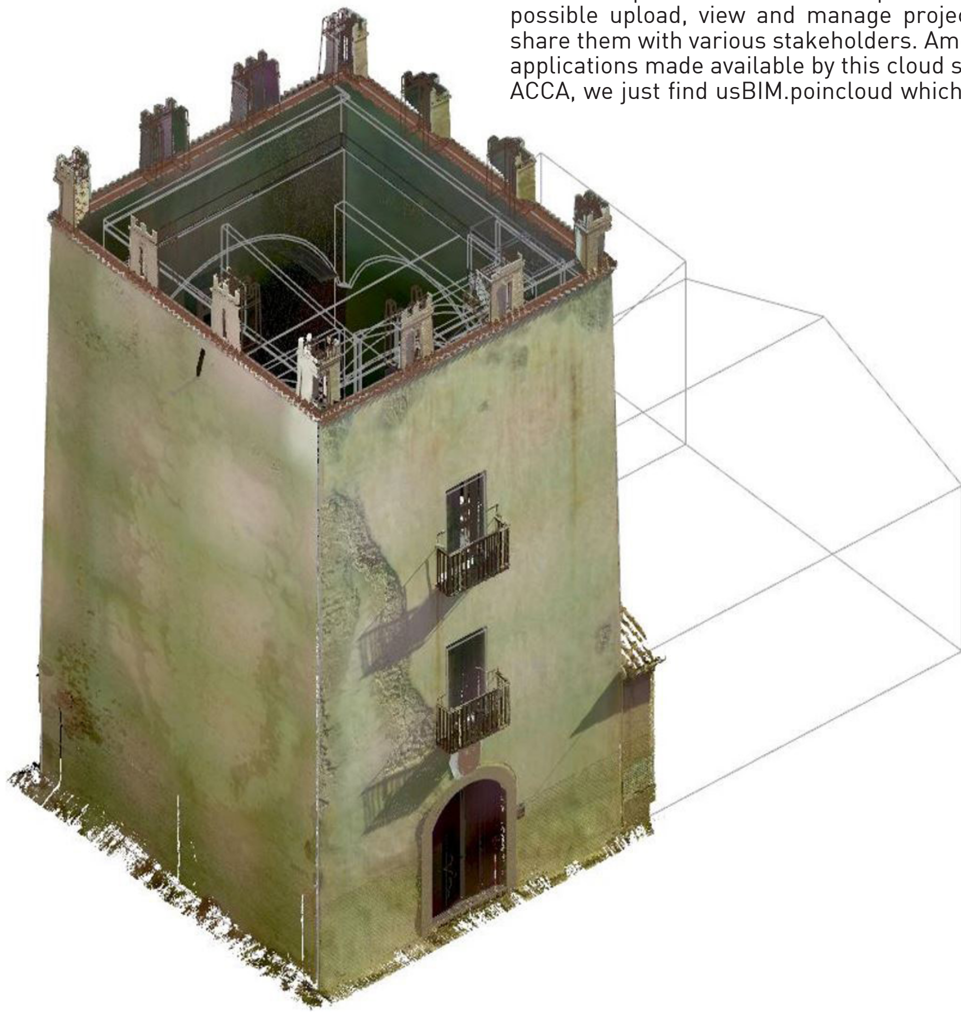

Figure 9. Modeling by point cloud with Edificius by ACCA Software S.p.a.

The first step to proceed to the modeling from points cloud is to upload it to usBIM.poincloud. UsBIM.poincloud is an usBIM application by ACCA Software S.p.a. UsBIM is a cloud space where it's possible upload, view and manage projects and share them with various stakeholders. Among the applications made available by this cloud space of ACCA, we just find usBIM.poincloud which allows

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to view and manage point clouds from browser. Once the point cloud has been loaded into the application, it is then imported into the BIM authoring software (Edificius by ACCA Software S.p.a. in the usBIM (d)) version. Here you can finally start with the modeling the different entities of the model (Fig. 9). As anticipated, the BIM modeling process from the point cloud is not automatic. The cloud acts as a geometric basis for modeling that takes place through the classic BIM Edificius software commands. The simultaneous display of the model and the point cloud allows you to achieve a high level of detail and reproduce with the greatest possible precision the irregularities of the tower.

During the modeling phase special attention was paid to the elements "exterior walls", "stairs" and "partitioned vault". The difficulties encountered are due to the different thicknesses and the inclination towards the interior of the perimeter walls and the peculiarities of the stairs and the vault. 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 consisting of a factory staircase (Fig. 11a). The modeling of such a characteristic constructive element, with ramps all different from each other, has been carried out by first modeling the ramps and stair landings in the architectural menu and then drawing the vaults in support in the specific editor. Another characteristic element is the partition vault on the second floor. The command inside the software allows to model this vault typology, but on a square base. However, from the point cloud it could be seen that the vault detected in the tower is characterized by an irregular plant. Therefore, once again, the irregularities of the building under study, typical of such an ancient good, required the study of alternative modelling techniques always respecting the properties related to the IFC classes (Fig. 10).
In detail, for the modeling of this vault a dome was built to cover the subtending area and then the

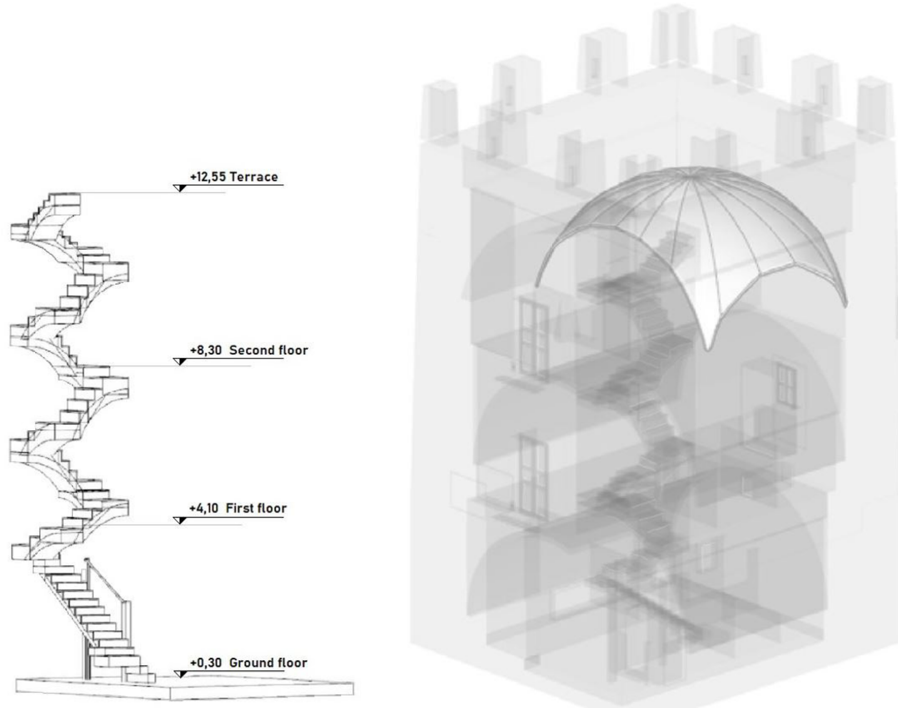

Figure 11. Staircases (a) and sail vault (b)of the Rame tower modelled from the point cloud with Edificius by ACCA Software S.p.a. (García-León et al., 2023).

	A	B	C	D
1	Pset Name	Property Name	Property IFC Type	Property Default Value
2	ProjectCommon	ConstructionModeTest	IfcPropertySingleValueIfcLabel	Relief on existing building
3	UsefulSurface	GroundFloor	IfcPropertySingleValueIfcAreaMeasure	39,1
4	UsefulSurface	FirstFloor	IfcPropertySingleValueIfcAreaMeasure	45,36
5	UsefulSurface	SecondFloor	IfcPropertySingleValueIfcAreaMeasure	48,24
6	UsefulSurface	Total	IfcPropertySingleValueIfcAreaMeasure	132,73
7	Historic	StartDateConstruction	IfcPropertySingleValueIfcInteger	siglo XIII
8	Historic	EndDateConstruction	IfcPropertySingleValueIfcInteger	siglo XVII
9	Historic	DateRenovation	IfcPropertySingleValueIfcInteger	2000
10	Designers	ArchitectRenovation	IfcPropertySingleValueIfcLabel	Féliz Santiuste de Pablos y Pedro Martinez Acosta

Figure 10. IFC, Pset created for the Rame tower with Edificius by ACCA Software S.p.a.

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sections outside the identified area were removed, using vertical cuts. Horizontal cuts were used to define the correct quota (Fig. 11 b).
To finish the graphic and realistic rendering of the HBIM model, some orthophoto renders were made (Fig. 12).
In the Heritage BIM section, within the Eidificius software, there is the command "ortofoto", this command allows to insert an orthophoto directly into the facade selecting it from the 3D.
Orthophotos must be prepared previously outside the Edificius software. In this case we proceeded taking photos with Canon SLR, each photo was then processed with Lightroom software with which we proceeded to the vertical and horizontal rectification and correction of distortion linked to the camera lens. The photos were combined with Photoshop to create the facade in full or in portions, as needed.
The application of the BIM methodology to the cultural heritage is still under development and improvement, which is why it was possible to make renders with orthophotos only with the version BIM 3 (e) of the ACCA's BIM authoring software "Edificius".

3.3.2. Degradation mapping

Given the complex and deep state of decay in which the Rame Tower is found, here we decided to focus on the pathologies detectable on the external face. For an initial identification, classification and nomenclature, an as international as possible glossary by ICOMOS-ISCS – International Council on Monuments and Sites, has been used.
It is necessary first of all to distinguish between decay and alteration. By alteration we mean a modification of the material that does not necessary imply a worsening of its characteristics from the point of view of conservation while decay is defined by ICOMO-ISCS as any chemical or physical modification of the intrinsic stone properties leading to a loss of value or to the impairment of use.

Referring to the glossary ICOMOS-ISCS, the following types of alteration and decay have been identified on the external face of the tower:
• Missing part subtype "gap" (decay): a type of degradation that is part, according to ICOMOS, of features induced by material loss. This type of degradation is defined as loss of continuity of surfaces (part of a plaster and a painting, ceramic coating, mosaic tiles, etc.).
• Rotting (decay): Alteration of the wooden element caused by the parasitism of microorganisms that leads to the destruction of the cells, cracking in various directions the wood and making it crumbly.
• Chromatic alteration: Natural variation, on the material components, of the parameters that define the colour. It is generally extended to all affected material.
• Graffiti (alteration): there are defined by ICOMOS as engraving, scratching, cutting or application of paint, ink or similar matter on the stone surface, are generally the result of an act of vandalism.
.
On the BIM modelling software Edificius, it is possible to identify the pathologies that affect the external face of the tower in parametric form and on the orthophoto associated with the parametric objects of the model (Fig.13).
The presence of orthophotos is not indispensable but helps in a more precise identification and definition of pathologies. Once the degradation area has been identified, the specific characteristics are assigned, referring to the glossary by ICOMOS-ISCS and defining properties such as:

Figure 12. Render of the Rame Tower HBIM, south view (a) and north view (b) made possible only with the version BIM 3 (e) of the ACCA's BIM authoring software "Edificius".

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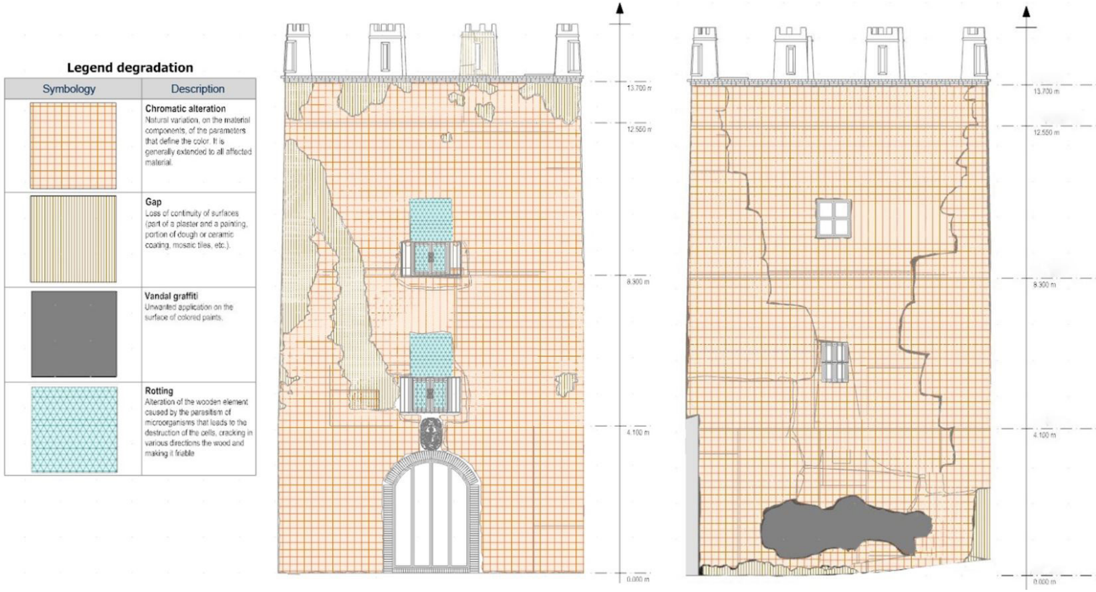

Figure 13. Degradation mapping on ACCA´s BIM authoring software Edificius, South facade (a) and North facade (b).

- Type: alteration or degradation
- Description
- Depth: additive or subtractive and thickness.

3.3.3. bSDD

The bSDD is a hierarchical dictionary of object concepts, their properties and allowed values used in BIM. Property sets are predefined by regulations agencies and vendors and extend common property sets of the Industry Foundation Classes (IFC).
The bSDD, this dictionary is being improved until a better semantic version of the dictionary is obtained (Alexiev et al., 2023), has 12 entities or object types, in 6 divisions:
1. Reference entities: Country, Language, ReferenceDocument, Unit.
2. Domain
3. Property: PropertyRelation and PropertyValue
4. Classification: object, material, component, ClassificationRelation: relation between classifications.
5. Classification Property
6. Classification Property Value

In this case, in order to demonstrate that a standardised and international codification of the conservation status of existing heritage is not only possible but also deeply necessary, a dictionary has been implemented that allows the communication, without misunderstandings, of degradation and alterations present on the facades of the Rame Tower.
The preparatory phase to the creation of the dictionary is obviously the identification of pathologies on the model, as seen in the previous paragraph. The use of the BIM authoring software (Edificius by ACCA Software s.p.a. in the usBIM (d)) allows to realize this phase in a BIM so that pathologies are not 2D objects but parametric objects, each with its own informative content.
The next step was to create the dictionary using usBIM.bSDDeditor. The creation saw the diction-

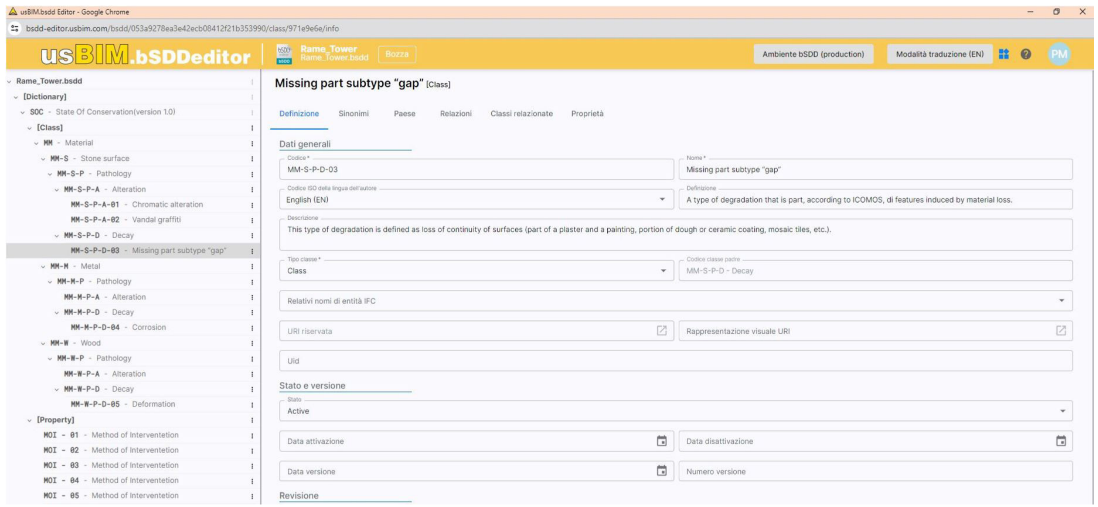

Figure 14. Creating the dictionary on usBIM.bSDDeditor.

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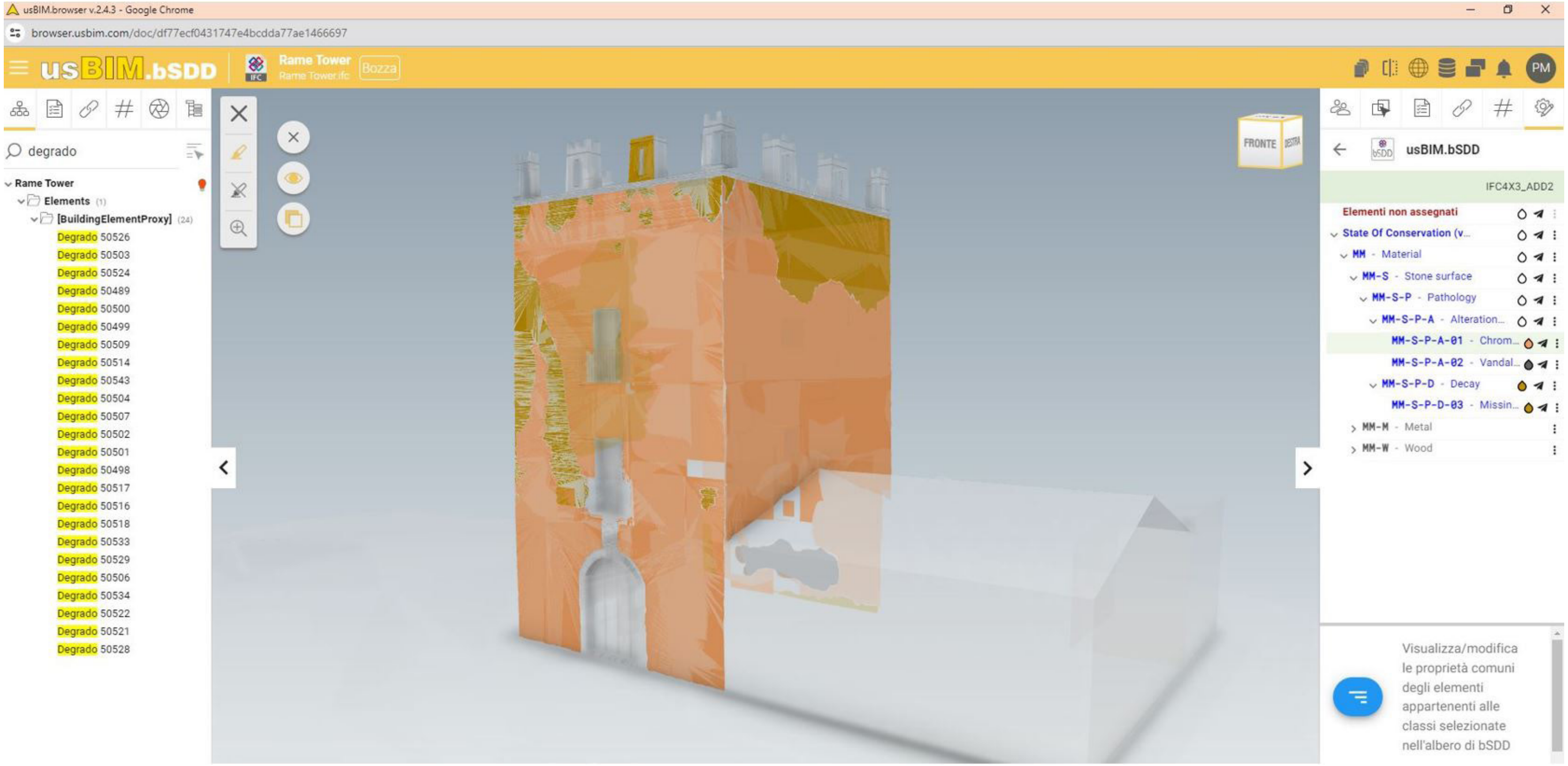

Figure 15. Association of the dictionary "SOC - State or Conservation" with the IFC model thanks to usBIM.bSDD.

ary organized into classes - defined by ISO23386 as 'description of a set of objects that share the same characteristics. '– subclasses, distinguishing the materials affected by the pathology and then distinguishing the pathologies between alterations and degradation, and properties defined by ISO23386 as 'an inherent or acquired feature of an item. Example: Thermal efficiency, heat flow, (...), colour.' as a first intervention suggestion for any pathology (Fig. 14). The dictionary thus created will have an extension .json (bSDD format). In order to respect a certain degree of internationality, the English language has been chosen to be the input language.

The next steps within usBIM.bSDDeditor were:

- Dictionary validation to check for errors;
- Loading the dictionary on bSI's online service for future use.

Let's remember that the aim is to make the work as international and interoperable as possible; therefore, the model of the Rame Tower in IFC format has been exported and at this point it's possible to apply the dictionary "SoC - State of Conservation" to the IFC model of the tower through usBIM cloud and in particular through usBIM.bSDD (Fig.15).

In the usBIM.browser space, therefore, we see simultaneously the IFC model and the domain classes created in bSDD, with their properties and possible typologies/values. You can now select the IFC model entities and assign them the bSDD dictionary entries. Each entry in the bSDD dictionary can be associated with a color that will be assigned to the entities that will be assigned that entry. This creates a semantic and thematic map that facilitates informative understanding. All added information in usBIM.bSDD is updated on the IFC model and the downloaded model will retain all data input.

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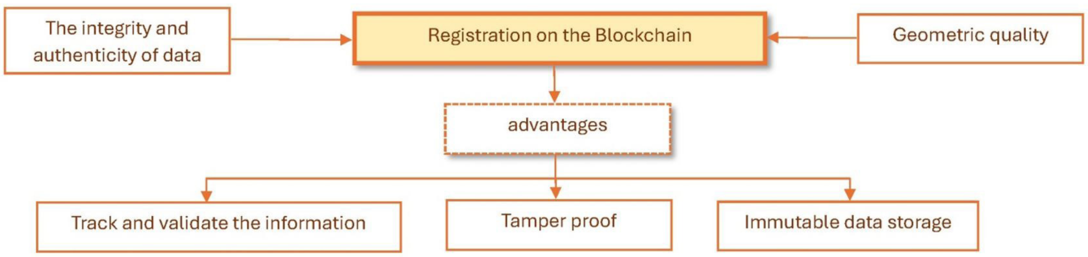

Figure 16. Blockchain.

3.4 Blockchain

The first step was to decide whether the project required the use of this technology for collaborative information exchange. The number of working groups involved the centralization of management and the volume of documentation to be used had to be taken into account. It is necessary to evaluate the effort of using this disruptive technology to provide a more efficient service, considering that it is not yet widespread.
In order to apply this methodology, it is necessary to determine the type of blockchain to be used (Turk & Klinc, 2017). This entails selecting between different degrees of decentralization and designing the work program and the data to be recorded.
In this instance, it has been determined that the data to be recorded will be two:
1. Those that certify the quality and origin of the historical, architectural and constructive documentation of the Rame Tower.
2. The documents that provide the geometrical quality of the finally generated HBIM model.
In this way, both information is stored and accessible, with the advantages that have already been mentioned in the introduction and which in our case are three (Fig. 16):
• Track and validate the information: Each information entered is recorded when it was made and who generated it, since a cryptographic digital signature is necessary.
• Tamper-proof: The information is decentralized in a multitude of computers (nodes), distributed in a network, so modifying all copies simultaneously is extremely difficult.
• Immutable data storage: The technology's own architecture means that each block contains a unique link to the previous one, so that if one wanted to change one block, all subsequent blocks would have to be changed. This fact would reveal that an attempt is being made to manipulate the information.
In this way, the HBIM, with guaranteed geometric quality and data authenticity can be consulted at any time during the execution of the project, particularly by those responsible for the heritage, thus facilitating future decisions based on the principles of collaboration and transparency.

4. RESULTS AND CONCLUSIONS

The historical heritage is characterized by heterogeneity and peculiarities typical of this type of asset that has seen and suffered the passage of time and the human activity. Therefore, when working with historic buildings, being able to communicate in a unique way and without misunderstandings becomes of fundamental importance but, at the same time, it is still an open challenge in the context of the BIM and openBIM standards-based methodology.
One of the most delicate aspects concerns the definition and communication of pathologies. Every pathology has a significant information content that must be able to communicate in the most universal way possible between the various stakeholders of the AEC sector, so that, for example, an approach to conservation based on clear and not misunderstood information.
In this research, therefore, we wanted to demonstrate that it is not only possible to implement standard formats, open and vendor-neutral, in the HBIM process but that this step is also strongly necessary. The implementation of open and standard formats in the openBIM workflow, in fact, applied to existing assets would ensure: the same interpretation, automatic data processing, comparison and learning.
Then, once the HBIM model has been finished and the pathologies have been defined in parametric form, a dictionary "SOC-State Of Conservation" has been created to encode the pathologies in bSDD standard format. The dictionary was then used to add standard information content to the exported template elements in IFC (another standard openBIM workflow format).
A characterisation has been achieved based on an international standard language that is interoperable, allowing all stakeholders to share and exchange information about the objects and their properties, increasing the future possibilities for coordination and collaboration. It is important to underline that regular validation and maintenance procedures are necessary to ensure accuracy and continuous updates.
The advantages of including blockchain technology are manifold. In our situation, we have focused our efforts on increasing data transparency by including certified records that prove the origin and quality of all data used to create the HBIM. In addition, intellectual property rights are incorporated into the flowchart, which helps to build trust between the parties involved. In addition, the certainty that the use of all this information in future interventions is unalterable and accessible.
Finally, the three-dimensional model and the HBIM of the tower have been made openly available to the public through the Zenodo platform at the following link https://doi.org/10.5281/zenodo.10937432.

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