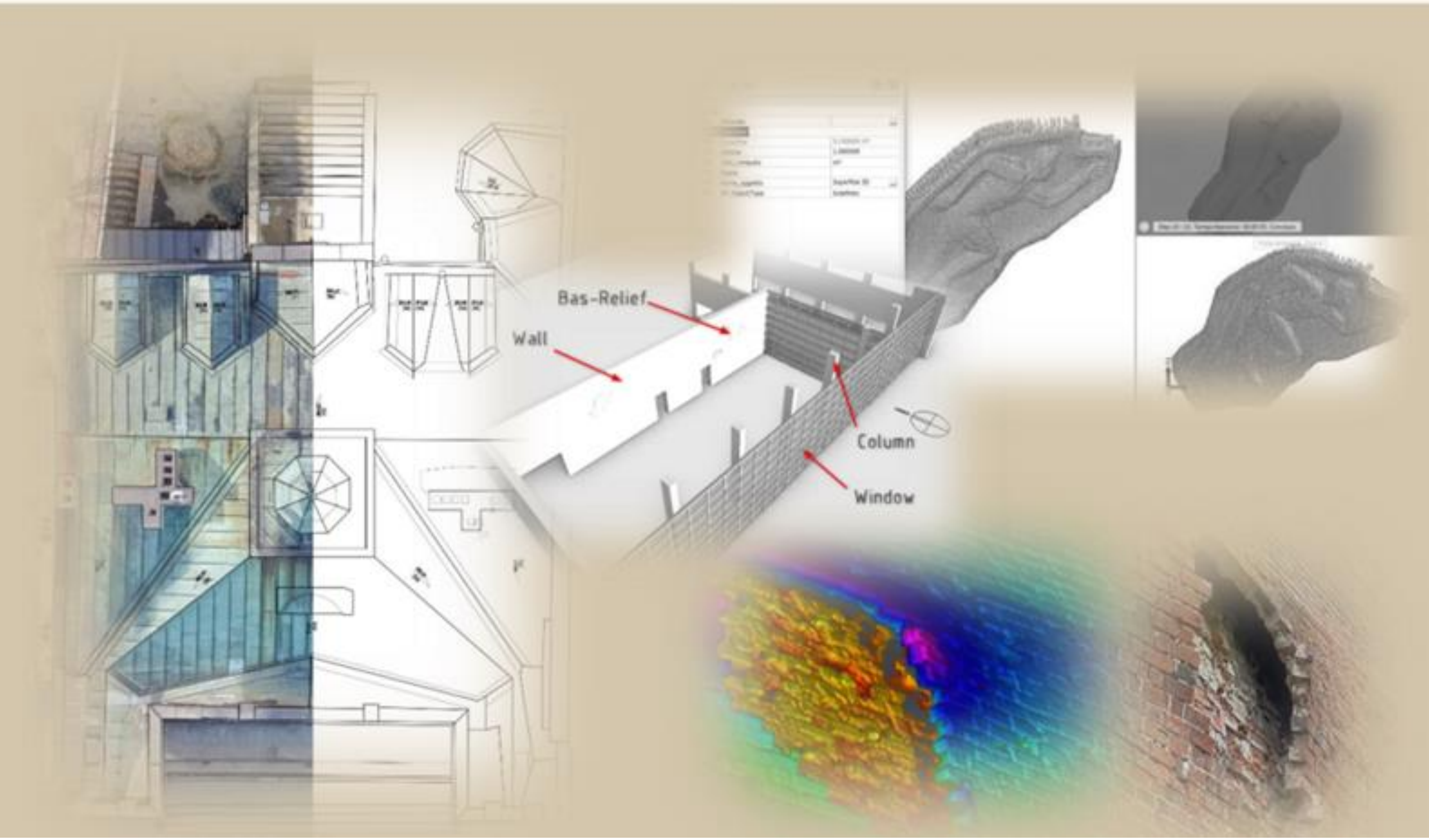
STAGES OF DOCUMENTATION FOR THE PROTECTION AND DEVELOPMENT OF HISTORIC BUILDINGS IN BIM SOFTWARE

Universal survey of historic object, supporting H-BIM modelling



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1. BIM as a technology for representation of existing objects - digital twins

In the heart of our expansive digital era, industries across all sectors are undergoing significant transformations. Particularly notable is the construction and infrastructure domain. Historically viewed as somewhat resistant to rapid technological shifts, it's now witnessing a tidal wave of innovation, and Building Information Modeling (BIM) stands out as a beacon of this change. While BIM was originally conceptualized to simplify and enhance design and construction processes, its role and utility have seen exponential growth and diversification over recent years.

Beyond its foundational principles, which focus on generating and managing digital representations of physical and functional attributes of a place or structure, BIM's evolutionary journey has taken it to new horizons. Today, it's not just a tool used in the preliminary stages of construction but an integrated system that spans the entire lifecycle of a structure, from its conceptualization to demolition.

This brings us to an exciting intersection of BIM and the concept of 'Digital Twins.' A digital twin is a dynamic, virtual representation of a physical object or system, capturing not only its tangible attributes but also its behavioral patterns and functional dynamics. And as the lines between the physical and digital worlds blur, the synergy between BIM and digital twins is becoming increasingly evident. With BIM's capabilities, creating a digital twin of an existing infrastructure or building becomes not just feasible but also efficient and detailed.

Several inherent advantages come with representing existing objects as digital twins via BIM. The most significant is perhaps the capability for real-time monitoring and data analysis. With a BIM-powered digital twin, stakeholders can access real-time data pertaining to the physical asset, allowing them to make informed decisions quickly. This real-time feedback loop is invaluable in emergency scenarios and for routine maintenance, ensuring the asset's longevity and optimal performance.

Beyond immediate response mechanisms, the predictive capabilities of this technology stand out. Through advanced simulations, BIM can forecast potential wear and tear or malfunctioning, allowing stakeholders to implement preventive strategies. This not only leads to cost savings in the long run but also ensures the safety and functionality of the asset.

Another aspect worth highlighting is collaboration. With BIM's detailed digital representations, various stakeholders, be it architects, engineers, contractors, or facility managers, can seamlessly collaborate. They can access, modify, and update the digital twin, ensuring that everyone is on the same page, reducing errors and streamlining operations.

Moreover, in today's world where sustainability isn't just a buzzword but a necessity, BIM's contribution is immense. By continuously monitoring energy consumption, water usage, and other environmental metrics, stakeholders can implement eco-friendly practices, optimizing resources and minimizing waste.

However, like all technologies, BIM and digital twins come with their set of challenges. The data deluge, due to the intricate detailing of assets, can sometimes be overwhelming, requiring advanced data management and processing solutions. Integrating new BIM data with legacy systems, especially in older infrastructures, can be a daunting task. Moreover, the continuous updates that digital twins demand can be resource-intensive, both in terms of technology and manpower.

Peering into the future, as the realms of the Internet of Things (IoT), Artificial Intelligence (AI), and machine learning expand, the relationship between BIM and digital twins is only poised to grow stronger. It's plausible to envision a future where autonomous systems self-update digital twins in real-time, where predictive analytics is so precise that it can pre-empt issues before they manifest, and where the line between the digital representation and the physical asset becomes incredibly thin.

In wrapping up, the journey of BIM from a design and construction tool to a pivotal technology in the creation and management of digital twins epitomizes the transformative power of technology. The challenges, though real, are surmountable, and the possibilities, endless. The convergence of BIM and digital twins is undeniably an exciting realm, set to redefine how we perceive and interact with our built environment.

2. H-BIM as a tool for assessing the state of preservation and value of a heritage

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Contemporary challenges related to the conservation and management of cultural heritage are extremely significant on a global scale. Historic buildings provide an important link to our past, representing the richness of cultural, historical, and architectural values. However, as tangible objects, they are susceptible to the passage of time, environmental conditions, human actions, and often suffer from neglect. Therefore, effective tools that enable the documentation, assessment, and management of these heritages are crucial.

Valuing cultural heritage, including historic buildings, is also extremely important. This is key as it allows for the appreciation and understanding of the historical and cultural value of our past. Assigning value to monuments also aids in promoting tourism and the local economy. Finally, it is a critical element of education, enabling us to understand and appreciate the diversity and wealth of our shared heritage.

The advent of digital technologies has contributed to a revolution in heritage conservation. Among these advancements, Historic Building Information Modelling (H-BIM) is a powerful tool for heritage protection and management. H-BIM is an evolution of conventional Building Information Modelling (BIM), tailored to meet the requirements of historic buildings and structures. It provides a comprehensive approach to collecting and managing data on historic buildings, enabling the creation of detailed 3D models that not only reflect the physical dimensions of the structure but also contain valuable information regarding its historical significance, materials, condition, conservation history, and more.

The basic principles and technical aspects of H-BIM, its potential in preserving and expanding our understanding of historic buildings, and its role in facilitating informed decisions regarding conservation strategies, through technical evaluation and historical valuation, will be discussed. Analysing various case studies will provide further evidence of the effectiveness and efficiency of digitisation in construction and H-BIM technology.

Today, where digital technology penetrates almost every sphere of our life, heritage protection also keeps pace. In the context of analysing and conserving historic buildings, Building Information Modelling (BIM) technology and its specific variant - Historic Building Information Modelling (H-BIM) - are becoming extremely important tools.

H-BIM is a technology that is constantly developing, as evidenced by numerous new studies and scientific publications on this subject. Academic papers analyse and develop H-BIM methodologies, contributing to the further development of this tool, which is increasingly used in the protection and management of cultural heritage.

For example, in publication [1] the focus is on the methodology and technology related to Building Information Modelling (BIM) that provide architects, engineers, and historians with concepts and tools to support the development of heritage projects.

A case study of the historic centre of Frigento by Elena Gigliarelli [2] shows how H-BIM can be used to identify systems and methods for improving the efficiency of historic buildings, including energy saving applications and integration of renewable energy sources.

Other publications like [1]–[4] also provide valuable information about the use of BIM and H-BIM technology in managing cultural heritage from different perspectives and in different contexts.

All these publications together create a rich picture of the possibilities that BIM and H-BIM technology offer in the context of working with heritage buildings. They show how these technologies can contribute to the preservation and protection of our heritage for future generations.

This chapter of the handbook focuses on the use of H-BIM as a tool for assessing the state of preservation and value of heritage, paying particular attention to the possibilities that this technology offers in the context of managing and conserving historic buildings.

2.1. Valuation of historic buildings

The valuation of historic objects is one of the most crucial activities in the entire preservation process. This is due to the fact that valuation is the basis for key actions undertaken with monuments – the selection of objects that attain heritage status; the determination of features and elements of monuments that should be preserved; the planning of conservation work; the justification of costs and the scope of work undertaken with monuments (in relation to stakeholders). The sum of these actions means that the analytical assessment of the value of a monument is extremely significant for its effective preservation, that is, the proper combination of conservation work with renovation work and adaptation to contemporary functions.

The valuation of monuments is a difficult task. This is due to several reasons. First and foremost, heritage objects represent very diverse values – technical, utility, financial, historical, documentary, symbolic, landscape, etc. These values belong to very different axiological systems. Moreover, creating a full catalog of values is difficult as their recognition depends on a wide range of stakeholders, thus it is subjective and variable over time. The measurement of individual values is also problematic. Only some values (such as technical or utility) are subject to objective evaluation, based on established norms, indicators. However, the assessment of most values (their measure) is subjective. An even bigger problem is comparing values of different nature. There is no system that would allow for comparing, for example, the utility value with landscape or technical value. Therefore, in monument preservation, no universal hierarchy of values of different characteristics has been established.

The problems associated with value assessment mean that no universal valuation systems have been introduced in monument preservation. Even in standardized monument documentation – for example, the justification for registering a monument – no scheme for determining the value of a monument has been introduced. As a result, in every process of dealing with a monument, determining its value is an individual activity, resulting from the specifics of the object, the approach of the conservation services, the needs and capabilities of the manager, etc. Such a situation does not, of course, serve the optimal preservation of the historical values of objects.

The complications presented do not undermine the need for value analysis as the basis for every monument preservation process. Value analysis should be conducted at the earliest stage of dealing with a monument, that is, already when giving it monument status. However, in practice, value assessment should be made at the stage of preparing detailed documentation / inventory of the monument. Therefore, the documentation/inventory made in the HBIM system should include the evaluation of heritage values. However, the diversity of heritage values means that the scope of their analysis should be adapted to the nature of the activities undertaken with the monument.

In the inventory in the HBIM system, technical values, i.e., the technical parameters of the monument as a construction object, are of crucial importance. Parameters determining the technical condition of the monument are determined (examined) and compared to standard values – any differences are the basis for determining the condition of the object (e.g. good, satisfactory, bad, disastrous) and the necessary conservation / renovation work. The completeness of the monument is also subject to evaluation, i.e., the preservation of the architectural form in relation to the original object. This feature – in monument conservation also treated as a value, is called integrity. Parameters covered by the concept of authenticity – include an assessment of the material, execution, location, decoration of the examined monument in relation to the original object.

The assessment of authenticity and integrity, resulting from the assessment of the monument at a technical level, is important for determining further values. The preservation of these features is the basis for documentary value – the most important of the so-called heritage values group. Documentary/scientific value is the value of an object (its elements, details, materials) as a subject of scientific research (currently and in the future). Obviously, the results of scientific research are credible only when the subject of research is unchanged. Authenticity and integrity of the monument (i.e., its state of preservation) also have some relevance to the historical value. Historical value is the value arising from events, figures, ideas associated with a given monument - the object's connection with historical facts can be a value for various communities. In such a case, the widely understood truthfulness of the place with which historical facts are associated is important for historical value. Another value based on the state of preservation of the object is the artistic value. Many monuments were works of architecture, representing quality and artistic value. The preservation of this value is, to some extent, a function of the state of preservation of the original object.

The three aforementioned values – scientific, historical, artistic – are defined as heritage values (these values are the basis of the definition of a monument in the Polish Act on the Protection and Care of Monuments – 2023). Their evaluation is not directly included in the structure of HBIM inventory, however, it may be included in the documentation in the form of additional folders / information attached to the characteristics of individual elements of the monument. The basis for evaluating these values is the state of preservation of the monument.

In a similar form, the utility values of the monument may be presented. The concept of utility values should be understood broadly, as a range of values related to the contemporary use of the monument. The set of utility values creates several groups of values, which result from the functions that the monument can perform. First and foremost, monuments can be a place of location / implementation of various utility functions (as buildings) - offices, museums, office buildings, catering, trade, accommodation, etc. Monuments can be used as a tourist attraction (sightseeing).

Monuments can serve educational/promotional functions, play symbolic roles, and be a contributing element to the identity (of a place, community). Finally, monuments can be the setting for various outdoor events (as a space).

In each of the indicated cases, the utilitarian function is also a value of the monument (realized or potential). These values (functions) are variable, so they are not part of the direct characterization of the monument, presented in the HBIM inventory. However, similar to heritage values, they can be presented in folders with additional information. Similarly, the economic value of the monument, which is even more variable, can be presented.

2.2. Technical condition assessment

The H-BIM model is not just a visualization of a building, but also a space where we add information about its technical condition in the form of parameters. Creating such a model requires taking several crucial steps, among which 3D scanning is one of the key ones. The results of 3D scanning are extremely useful in assessing the technical condition, as they recreate the object under study with incredible precision, along with any damage present in it. This method allows for an accurate, three-dimensional visualization of the monument, thereby facilitating its analysis and planning of conservation actions.

In this chapter, the focus is on presenting methods for assessing the technical condition of heritage objects, using modern digital technologies. Particular attention has been paid to the process of implementing the Historical Building Information (H-BIM) model, which is becoming increasingly popular in the context of cultural heritage management. This model, as an expanded system of parameters, enables the integration and presentation of data related to the technical condition of the object.

The H-BIM model has many advantages, but one of the most important is its ability to systematize information. Thanks to this tool, it is easy to collect, process, and analyze data about historic buildings. Unfortunately, the main problem in this process is the lack of systematization of data collection methods. There is often a lack of consistency and uniformity in the information gathered, which complicates a full analysis and understanding of the history and value of these unique buildings. To effectively use the H-BIM model, it is necessary to introduce more consistent and precise data collection methods in order to fully utilize its potential and ensure accurate and reliable results.

The lack of a standard for documentation related to the technical assessment of heritage objects is a global problem that hinders effective management and conservation of cultural heritage worldwide. This issue has significant implications for the protection and preservation of historic buildings, as the lack of consistent and uniform guidelines and standards makes it difficult to properly identify, evaluate, and document the condition of these objects.

One of the main problems resulting from the lack of a documentation standard is the inconsistency in the way data and information about heritage objects are collected. Different countries, regions, or even institutions may have different methods and criteria for the technical assessment of monuments, leading to heterogeneity and difficulties in comparing and exchanging information. As a result, this lack of consistency hampers effective analysis and decision-making regarding assessment, valuation, conservation, and management of historic buildings.

Additionally, the lack of a documentation standard leads to difficulties in identifying and tracking changes in the technical condition of heritage objects over time. The absence of consistent and clear protocols and guidelines for documenting and reporting results in the loss of significant information, making it much more challenging to monitor and evaluate the condition of historic buildings. As a result, there is a risk of losing unique data that could be used for a better understanding and protection of cultural heritage.

The lack of a documentation standard also affects the effectiveness of collaboration and knowledge exchange between various institutions, researchers, and practitioners dealing with cultural heritage.

Without uniform guidelines and documentation formats, it is difficult to communicate effectively and share information regarding the technical assessment of historic buildings. This hampers international cooperation and the exchange of best practices and experiences.

To solve this global problem, there is a need to develop consistent documentation standards and guidelines for the technical assessment of heritage objects. Such standards should take into account international norms, principles, and best practices in the field of conservation and cultural heritage management. Introducing uniform standards would facilitate data comparability, streamline information exchange, and enable better monitoring and protection of historic buildings worldwide.

One solution in Europe that could contribute to improving this situation is the PN-EN 16096 standard concerning technical documentation for assessing the technical condition of heritage objects. Although not widely used, this standard provides recommended guidelines for documentation related to the technical assessment of historic buildings. Its implementation could lead to more consistent and uniform documentation, facilitating the analysis, comparison, and exchange of information about the technical condition of heritage objects.

However, it should be noted that the PN-EN 16096 standard is not currently widely used and is not mandatory. It is merely recommended as a guideline for engineers and architects dealing with the technical assessment of historic buildings. In practice, there is still a lack of consistency in documentation, hindering effective management, monitoring, and protection of cultural heritage on a global scale.

The assessment of the technical condition of heritage objects is a complex process that typically involves several stages. Below is a general list of steps that should be taken.

- Inventory: The first step is a thorough recognition and description of the object's characteristics. This includes archival documentation, as well as its historical and cultural value. The inventory may also include photographs, drawings, maps, and other visual materials. Currently, 3D scanning is recognized as the most accurate form of inventorying historical objects. With this technology, it is possible to precisely reproduce the shape, details, and geometry of historic buildings in the form of a three-dimensional digital model. 3D scanning allows even the smallest elements and nuances to be captured, which are often difficult to include in traditional inventory methods.
- Preliminary inspection (site visit): A visual inspection of the historical object can help identify obvious problems and issues that may require further evaluation. The preliminary inspection takes place during a site visit to the object.
- Detailed evaluation: This phase involves a thorough examination of the object to identify any potential problems. Given the complexity of historical objects, a team of experts is often required to correctly recognize all elements and diagnose existing issues. A detailed evaluation also necessitates in situ (on-site) and laboratory investigations. Nowadays, geodetic studies of displacements and deformations can be successfully replaced with point clouds generated during precise field scanning.
- Technical condition analysis: All previously collected data is subjected to analysis. A meticulous and detailed examination of the collected materials not only allows for a better understanding of the object but also helps identify problems and threats present within it.
- Technical assessment and recommendations: Based on the results of the technical status assessment, a technical document is created which includes detailed information about the state of the object and recommendations regarding necessary conservation, repair, or renovation actions.
- Action planning: The final step is to develop an action plan based on the recommendations provided in the report. This plan should include a schedule, a cost estimate, and detailed information about the planned actions.
- Monitoring and reviews: After the completion of conservation, repair, or renovation actions, it is important to regularly monitor and review the object to ensure that any problems are quickly identified and appropriately addressed.

2.2.1. Inventory in technical condition assessment

Inventorying is a crucial phase in the technical evaluation process of historical objects. It's the precise gathering of information about an object, encompassing both the analysis of archival documentation and the appraisal of its historical and cultural value.

The first step in inventorying involves collecting as much historical documentation related to the object as possible. This requires seeking out archival plans, drawings, photographs, legal documents, letters, diaries, eyewitness accounts, and local legends and stories. These sources provide valuable insights into the object's history, its original purpose, past renovations, and changes it underwent over the years.

The next step is to conduct a detailed architectural description of the object. During this phase, special attention is paid to distinctive architectural elements such as roofing structures, load-bearing walls, ceilings, windows, doors, stairs, fireplaces, decorations, and architectural details. It's also important to document the materials used, building techniques, and the condition of individual elements.

The inventory process also involves creating photographs and drawings of the object, which form a significant part of the visual documentation. Photographs should capture various perspectives, including aerial views if possible. Drawings should contain floor plans, sections, and views of elevations, providing a visual representation of the object.

The final, but no less essential, element of the inventory is the evaluation of the object's historical and cultural value. Every historic object is an integral part of a broader cultural and historical context, and understanding this context is crucial in making informed decisions about conservation.

Today, 3D scanning has become the fundamental method for inventorying historic objects. With this technology, point clouds are created that provide detailed data about the shape and geometry of the studied objects. These point clouds constitute a valuable information source that can be used for various purposes. For instance, they enable the technical assessment and valuation of historic objects, crucial for the conservation and protection process of cultural heritage.

Thus, 3D scanning not only provides precise inventory data but also opens up new possibilities in studying, documenting, and preserving historical objects.

2.2.2. Preliminary inspection (site visit)

Preliminary inspection, also known as an on-site inspection, is a critical step in the process of assessing historic objects. As part of this inspection, an initial evaluation of the technical state of the object must be conducted before more detailed studies take place.

During the preliminary inspection, an assessment of the object's preservation state is necessary, identifying any visible damages such as cracks, deformations, water damage, erosion, and other potential threats to the structure of the object. This evaluation is crucial for developing an appropriate plan for further investigation – a more detailed analysis and technical condition assessment.

One of the key aspects of the preliminary inspection is recognizing the potential for using 3D scanning. Not all historic objects are suitable for 3D scanning. Often, this depends on the specifics of the object, its preservation state, and accessibility to different parts of the object. Therefore, during the preliminary inspection, it is essential to accurately assess whether 3D scanning is possible and if it will provide expected benefits.

In conclusion, the preliminary inspection is a crucial stage when working with historic objects, allowing for an evaluation of the object's technical state and recognition of the potential for using modern technologies such as 3D scanning. It's a process that requires significant experience and specialist knowledge, but it's indispensable for ensuring proper protection and conservation of cultural heritage..

2.2.3. Analysis of the technical condition of historic buildings

The assessment of the technical condition of historical sites is one of the most important conservation issues, forming the basis for fundamental decisions related to the protection of the monument. These decisions include defining the extent of necessary interventions in the form and substance of the monument, planning conservation and repair work, and choosing the form of adaptation of the object to contemporary functional use. The assessment of technical condition is not the only factor, but it is important and often even decisive.

In the case of historic buildings and architecture, the assessment of the technical condition is conditioned on two levels. The first condition relates to issues associated with the condition of the monuments as structures. These are strictly technical issues – geotechnical, structural, material, technological, etc. In the case of these engineering problems, the historical object is treated much like any other structure. The parameters determining the condition of building materials and structures, such as strength, humidity, salinity, adhesion, insulation, or, for example, cracking, deflection, sagging, settling, are important.

However, the assessment of the technical condition of historical structures cannot be reduced solely to engineering issues. The need to preserve the object in accordance with the requirements of authenticity and integrity – that is, the overriding principles of conservation – often influences the scope of the technical assessment.

Technical studies of historical sites are often more extensive and accurate, resulting from the adoption of specific conservation technologies or materials, which may require in situ analysis and laboratory testing. Additional conditions resulting from the need to carry out conservation work and the special value of historical sites mean that their technical condition assessment is an important, responsible and often non-obvious task.

After conducting a detailed examination of the historical object, a key stage in the evaluation process follows, which involves the analysis of the technical condition. At this stage, an in-depth analysis of the collected data is carried out to gain a full understanding of the condition of the object.

A structural assessment is essential to understand the stability and safety of the object. In this process, evidence of potential problems such as cracks, settlement, deformations, water or moisture damage, and any other factors that may affect the structural integrity of the object should be sought. This assessment is crucial to understand whether the object is safe to use and what actions may be needed to ensure its long-term stability.

The analysis of the state of architecture is a process in which the degree to which the object has preserved its historical features and value is assessed. The state of preservation of various elements of the object, including building materials, architectural details, finishes, as well as interior equipment elements should be assessed. This analysis allows understanding what elements of the object are most valuable from a historical point of view and which of them require the most urgent conservation.

Identifying potential threats is another key element of the technical condition analysis. This can include threats related to fire, flooding, pests, and factors such as exposure to adverse weather conditions or the impact of human activity. Identifying these threats is essential to develop effective risk management strategies and conservation action planning.

Based on the collected information, conclusions about the general technical condition of the object should be formulated. These conclusions should include recommendations for any necessary actions, such as repairs, conservation work, changes in the use of the object or proposals for further research. These conclusions and recommendations form the basis for further actions aimed at protecting and preserving the historical value of the object.

Systematic data collection about the object is extremely important, especially in the context of monuments and objects of cultural significance. This allows for a precise understanding of the state of the object, its historical and cultural significance, as well as potential threats to its preservation.

Earlier publications of this project, including "The Sheet of the Technical Condition Assessment for the Historic Building" emphasize that data collection should cover various aspects of the object, such as its architectural elements, materials, construction techniques, as well as information about its history and cultural context. All this information should be collected and analyzed synthetically to ensure the most complete understanding of the object.

There are many standards and methodologies that can assist in this process. One of them is the European standard EN 16096:2012, which provides a detailed framework for the technical condition assessment of historical sites. This standard is especially useful as it considers not only the physical condition of the object but also its historical and cultural significance. This way, it complements other standards and methodologies, helping to ensure the most comprehensive and accurate understanding of the object.

During the technical condition assessment of the object, the standard suggests dividing it into various building components, such as foundations, walls, columns, arches, floors, roof structures, etc. Each of these components is then assessed in terms of three key aspects, represented by the symbols CC, UC, and RC.

- CC - Condition Class: This abbreviation refers to the classification of the condition of a certain component of the building. The condition class is an assessment of the state of preservation of a given structural element. It can encompass various levels, from an ideal state, through different degrees of damage, to a critical state.
- UC - Urgency Class: This abbreviation is used to determine the degree of urgency in taking action to remedy the current state of the component. The urgency class indicates how quickly repair or conservation actions should be taken to prevent further deterioration of the element. It can include various levels, from actions that require immediate attention, through actions that can be planned for the future, to actions that are not urgent.

- RC - Recommendation Class: This abbreviation is used to classify the recommended actions that should be taken to manage the condition of the component. The recommendation class specifies the type and scope of actions that are recommended to improve the condition of a given element. It can encompass various levels, from minor conservation actions, through major repair works, to comprehensive renovation.

Thanks to this standard, the technical condition assessment of a building becomes more structural and systematic, which allows for a better understanding of the building's condition and the implementation of appropriate actions for its protection and preservation.

However, it is important to remember that no standard or methodology is sufficient on its own. Each building is unique and requires an individual approach. Therefore, when gathering data about a building, it is important to adapt the process to the specifics of that building, taking into account its unique features and context.

2.2.4. Implementation and use of h-bim in assessing the technical condition of historic buildings

H-BIM, or Heritage (or Historic) Building Information Modeling, is an advanced tool used for estimating the technical condition of heritage buildings. It offers the possibility of creating three-dimensional digital models, which effectively assist in fully understanding a building's structure, its historical value, and facilitate the conservation management process.

The process of creating an H-BIM model begins with an accurate registration of the physical condition of the heritage building. Both traditional measurement techniques and modern methods such as 3D laser scanning can be used for this purpose. Based on the collected data, a digital model of the building is created, which is a faithful reflection of its physical structure and architectural details.

Once created, the H-BIM model is used for analysis and assessment of the building's technical condition. Using the potential of BIM technology, simulations can be conducted that help understand the impact of various factors on the building, such as loads, weather conditions, or variable usage conditions.

Analysis and assessment of the technical condition of heritage buildings using H-BIM have a multidimensional character. It takes into account structural aspects, historical aspects, and potential threats. Historical analysis, based on the H-BIM model, allows for a deeper understanding of the building's evolution over the years. It examines changes in the interior layout, architectural style, and materials used, which are crucial for maintaining the historical value of the building. The assessment of potential threats involves identifying and evaluating the risk that may arise in the context of the heritage building.

The use of H-BIM in the analysis and assessment of the technical condition of heritage buildings provides more precise and comprehensive results than traditional methods. It gives professionals better tools for understanding the building's condition and planning conservation actions, thereby contributing to better protection and preservation of heritage buildings.

H-BIM is also used for the conservation management of the heritage building. It allows for planning and monitoring various conservation actions, as well as predicting their impact on the building. H-BIM can also facilitate communication between various stakeholders, such as conservators, engineers, architects, and investors.

Lastly, it's worth emphasizing that the H-BIM model is a dynamic tool - it can be constantly updated and developed. As we gain new information about the building, for example, through further research or the implementation of conservation works, the model can be adjusted to reflect the building's actual state as accurately as possible.

In summary, H-BIM is a powerful tool that greatly facilitates the assessment of the technical condition of heritage buildings and the management of their conservation process. Its use can bring significant benefits, not only through improving the accuracy of the assessment but also through effective planning and monitoring of conservation actions.

2.3. Examples of technical assessment using digital technology

The use of digital scanning methods and BIM (Building Information Modeling) technology offers a range of possibilities for assessing the technical condition of buildings. Here are some of these possibilities:

- Accurate reproduction of geometry and details: 3D laser scanning allows for precise recording of the geometry and details of a building. This enables accurate representation of both external and internal elements of the construction. The digital BIM model incorporates this information, enabling visualization of the object in an accurate and realistic manner.

- Structural Analysis: BIM technology allows for conducting a structural analysis of a building. Based on the BIM model, different scenarios of structural loads can be simulated. This enables the assessment of the building's strength and stability and the identification of any potential structural problems.
- Thermal and Energy Analysis: Using thermal scanning technologies and data from the BIM model, a thermal and energy analysis of the building can be conducted. This allows for the identification of areas with low insulation, thermal bridges, or ventilation problems. Consequently, appropriate corrective measures can be introduced, and the building's energy efficiency can be improved.
- Condition Analysis: The digital BIM model enables monitoring and analysis of the heritage building over time. Comparing data from different periods allows for the identification of any changes, damages, or degradation. This enables conservation and repair planning based on the actual needs and technical condition of the building.
- Visualization and Presentation: Thanks to BIM technology, the digital model of the heritage building can be visualized in various forms, such as virtual reality, animations, or 3D visualizations. This facilitates a better understanding of the building, attractive presentation, and the transmission of information about the technical condition and necessary conservation actions.

Parameterized models made in BIM technology also provide a basis for carrying out design studies concerning repairs, renovations, and reconstructions of the scanned objects [5], [6].

Proces parametryzacji surowych chmur punktów do technologii BIM [7]

2.3.1. Technical assessment of a building

In this section, the potential use of specific digitization methods is presented:

- The use of spherical and aerial photography for the documentation of the condition of individual elements,
- Implementation of point clouds for inventory purposes,
- Transforming batches into planes in the form of orthophotoplans and views for graphical damage inventory,
- Studies on the deflection of structural elements,
- Investigations of deformations on surfaces.

The following part of the text will discuss the possibilities that digitization brings in heritage buildings. Additionally, methods for assessing the technical condition of buildings based on a predefined H-BIM model will be presented.

2.3.2. Spherical and aerial photography as documentation of the condition of elements

Spherical photography demonstrates substantial potential in the field of photogrammetry and has significant applications in preserving cultural heritage and protecting immovable monuments. It is a technique that enables comprehensive and accurate visual documentation of monuments, contributing to the creation of full panoramic images and 3D models.

The first benefit of using spherical photography is the ability to create detailed visual documentation. This technique allows for the capturing of images with a wide field of view, enabling the recording of all essential elements and details of the monument. Therefore, spherical photos represent a complete visual record, which can be used for analysis, examination, and reconstruction of monuments.

Another crucial advantage of spherical photography is the ability to create precise 3D models. Using a collection of spherical photos, advanced photogrammetry techniques can be employed to generate accurate three-dimensional models of monuments. These models can be used for virtual reconstructions, spatial analysis, damage identification, and the reproduction of architectural details.

In the field of immovable monument protection, spherical photography plays a significant role. It allows for precise documentation of the state of monuments, enabling the monitoring of potential changes, damages, or degradation. In the event of necessary repairs or conservation work, spherical photos can serve as a reliable source of information, facilitating precise planning and execution of actions, thereby minimizing the risk of damaging the monument.

In conclusion, spherical photos in photogrammetry represent a valuable tool in cultural heritage preservation and the protection of immovable monuments. With the ability to create full panoramic images and 3D models, spherical photos allow for comprehensive visual documentation and precise analyses of monuments. Therefore, they make a significant contribution to the study, reconstruction, and protection of cultural heritage, helping to preserve these valuable historical elements for future generations.

Drones are commonly used in the technical condition assessment of objects [8], [9].

Figure 1 Przykładowy zakres obejmowany przez fotografię powietrzną (fot. M. Wac)

Figure 2 Przykładowy zakres obejmowany przez fotografię sferyczną (fot. M. Wac)

- Example of Aerial Photographic Documentation

Aerial photographic documentation is an incredibly valuable tool in assessing the technical condition of heritage objects, especially those with hard-to-reach elements such as roofs, towers, or cornices. This method involves taking a series of photos from the air, typically using unmanned aerial vehicles, known as drones, equipped with high-quality cameras.

Consider the case of the Town Hall, where aerial photographic documentation was conducted to accurately assess the technical condition of elements located on the building's roof. The use of this method overcame the barrier presented by the lack of direct access to these areas.

Images taken with the drone provided incredibly detailed information about the condition of these elements. Each shot allowed a close examination of details - for example, the condition of the roof covering, the state of bricks, the degree of material degradation, or the presence of undesirable organisms like moss or lichens. The photos were clear and high quality, enabling a precise understanding of these elements' condition.

Furthermore, aerial photos are an invaluable source of information for creating an H-BIM model. Using appropriate techniques such as photogrammetry, these photos can be converted into three-dimensional models, allowing for an even more precise understanding of the structure and condition of the object.

Another key aspect of aerial photographic documentation is the ability to create images in various light ranges. For instance, infrared images can help detect issues related to moisture or heat loss, suggesting hidden structural problems. Ultraviolet images, on the other hand, can serve to identify damage induced by solar radiation, which might escape our visual perception. Simultaneously, images obtained using LIDAR technique can provide accurate topographic and three-dimensional data. In this way, aerial photographic documentation becomes a valuable tool [10], [11].

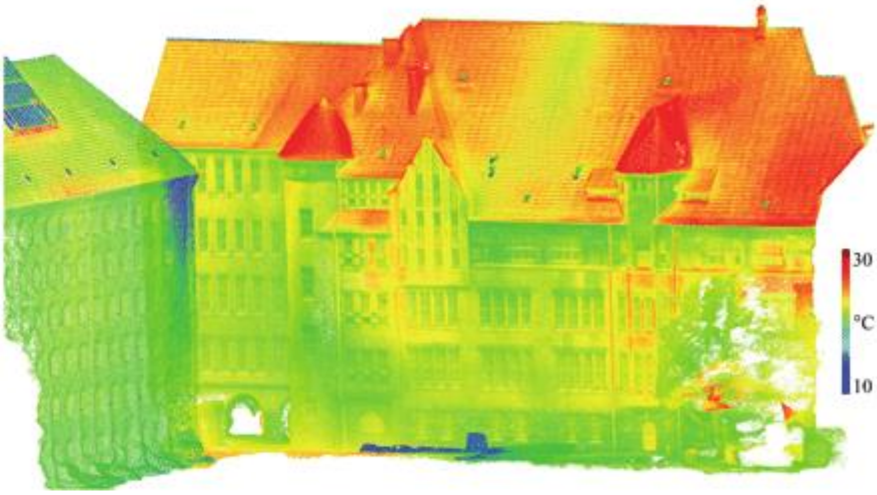


Figure 3 Model termiczny obiektu zabytkowego [10]

Aerial photographic documentation, therefore, serves not only as a tool for assessing the technical condition of an object, but also as a valuable source of information that can be used for planning and monitoring conservation work. Moreover, it enables the constant update of the object's condition, which is extremely important in the case of buildings of great historical value.

Below are examples of damage identified during a drone flight around the Town Hall building in Krasnystaw.

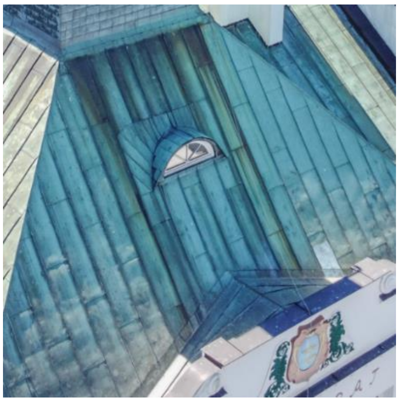


Figure 4 Zacieki na powierzchni połaci przy wieży zegarowej spowodowane brakiem odpowiedniego odprowadzenia wody opadowej (fot. M. Wac)

Figure 5 Zniszczenie i rozszczelnienie połączenia połaci ze ścianą sąsiedniego budynku spowodowane niewykonaniem odpowiedniego rodzaju obróbki (fot. M. Wac)

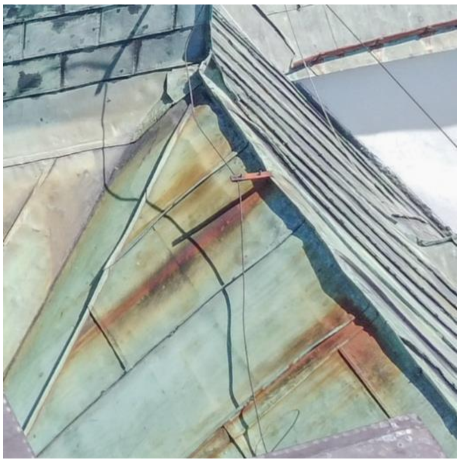


Figure 6 Osady z wypłukiwanej korozji na elementach montażowych instalacji odgromowej w okolicach kalenicy (fot. M. Wac)

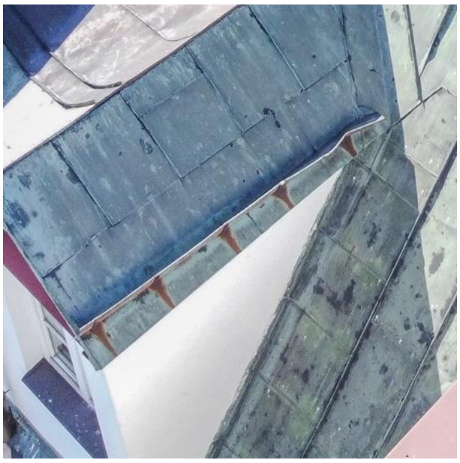


Figure 7 Elementy montażowe pokrycie z poszyciem powodujące rdzawe zacieki na połaciach (fot. M. Wac)

- Example of spherical photographic documentation

The use of spherical photography in narrow and poorly lit interiors of roof trusses brings numerous benefits, which significantly streamline the process of element identification and technical condition assessment. As part of subsequent processing and analysis, spherical photography allows for the precise determination of the location and type of elements, which shortens time and improves the efficiency of actions.

The first benefit of using spherical photography is the ability to easily identify the location and type of structural elements. Due to limited space and insufficient lighting, traditional identification methods can be difficult or time-consuming. However, thanks to spherical photography, the entire interior of the roof truss can be captured in one image, allowing a detailed look at all structural elements. In this way, spherical photos serve as a visual representation of the truss interior, which facilitates the process of identification and analysis.

Another important aspect of using spherical photography is limiting the need for a thorough search of the entire truss to find damage. Spherical photos capture a large area, allowing for a detailed and comprehensive consideration of the entire roof truss. In this way, potential damage or defects can be identified during the later analysis of the photos, which reduces the need for a long and time-consuming examination of the structure during a physical stay on the truss.

The use of spherical photography in narrow and poorly lit interiors of roof trusses brings significant benefits. Thanks to this technique, the identification of the location and type of elements becomes more precise and effective, shortening the analysis time. Moreover, spherical photos greatly reduce the need for a thorough search of the truss interior, allowing focus on the analysis of captured damage. As a result, the process of identification and technical condition assessment becomes more efficient and accurate. Spherical photos can also serve in building 3D models.

Figure 8 Zmiana zabrawienia drewna na krokwi koszowej, świadcząca o występowaniu rozkładu brunatnego na elemencie konstrukcyjnym (fot. M. Wac)

Figure 9 Znacza degradacja elementów konstrukcyjnych wieży zegarowej wraz z rozkładem brunatnym (fot. M. Wac)

Figure 10 Znaczące osłabienie przekroju poprzecznego płatwi spowodowane czopem po brakującym elemencie wspornym (fot. M. Wac)

Figure 11 Całkowite zdegradowanie krokwi, widoczna próba częsciowej naprawy i wzmocnienia elementu (fot. M. Wac)

2.3.3. Implementation of point clouds for inventory purposes

The use of point clouds for inventory purposes is a significant achievement in the field of project documentation. The methods of creating point clouds, described in the above context, enable the generation of precise substrates that preserve the accuracy of dimensions, angles and proportions.

The main benefit of using point clouds is the ability to create traditional design documentation with greater precision and accuracy. In the traditional approach to creating design documentation, there are often some distortions, due to the difficulty of accurately representing real dimensions and proportions. However, by using point clouds, it is possible to obtain more reliable and accurate data that can be used as a substrate for creating traditional design documents.

In the publication [6], it is emphasized that the creation of point clouds allows for the precise representation of complex architecture. In particular, the ability to register point data based on two-dimensional drawings allows for the precise representation of the geometry and structure of objects. This means that the created substrates are more reliable and accurate, which affects the quality of the final design documents.

The conclusion is that the use of point clouds for inventory purposes represents a significant progress in the field of project documentation. Thanks to this approach, it is possible to create traditional design documentation with greater precision and accuracy, which in turn translates into better understanding and interpretation of the designed structures.

The creation of a point cloud is actually one of the first stages in the process of creating a digital twin, also known as a digital twin. This technology is particularly important in the context of Heritage Building Information Modeling (H-BIM), where a detailed and accurate representation of a historic object is key to further analysis and management of the conservation process.

A point cloud is a set of points in space that together create a three-dimensional representation of an object. Each point in a point cloud represents a specific point on the surface of the object and is defined by its X, Y and Z coordinates. The set of these points, when viewed as a whole, creates an accurate image of the object.

The creation of such a point cloud is possible thanks to 3D laser scanning technology, which allows for the precise registration of a physical historic object. The scanner emits a laser pulse and measures the time it takes for the wave to travel from the emission to the reflection and return, which allows for the precise registration of the location of the points on the surface of the object.

Every historic object that is modeled in H-BIM technology most likely has a created point cloud.

This is a fundamental stage in the modeling process, which allows for the creation of an accurate and detailed representation of the object. The point cloud forms the basis for further modeling and analysis of the object.

In addition, the point cloud is incredibly useful in the case of historic objects that are exposed to various threats, such as erosion or damage caused by atmospheric factors. Thanks to the point cloud, it is possible to create an accurate copy of the object, which enables its reconstruction in the event of damage [12]. This is one of the main applications of H-BIM technology in the protection of cultural heritage.

It is also worth emphasizing that 3D laser scanning, which generates a point cloud, is a non-invasive process. It does not require direct contact or touching the object, which minimizes the risk of damaging historic materials and structures. This aspect is of great importance in the case of objects of particular historical and cultural value, which are particularly sensitive to conservation activities.

The point cloud also provides complete information about the historic object. It registers all of its geometric aspects, including every detail and nook and cranny. Thanks to this, technical condition analyses and documentation of historic objects become more accurate and precise. The point cloud allows for the identification of damaged areas, planning repairs or reconstructions, as well as monitoring changes in the object over time.

In addition, the point cloud enables the archiving of data and easy access to it in the future. Accurate and comprehensive data on a historic object can be used in research, reconstructions or making information about the object available to the general public. This in turn contributes to the development of research, educational and reconstruction processes related to cultural heritage.

The point cloud is a tool that is gaining increasing recognition in the field of cultural heritage conservation. Its precise documentation, analysis and preservation of historic objects represent a significant contribution to the protection and research of our cultural heritage.

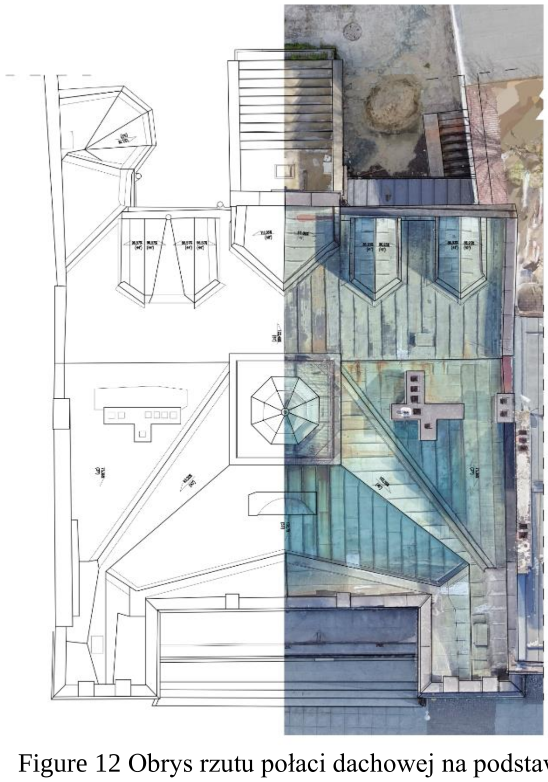


Figure 12 Obrys rzutu połaci dachowej na podstawie podkładu wykonanego metodą fotogrametrii

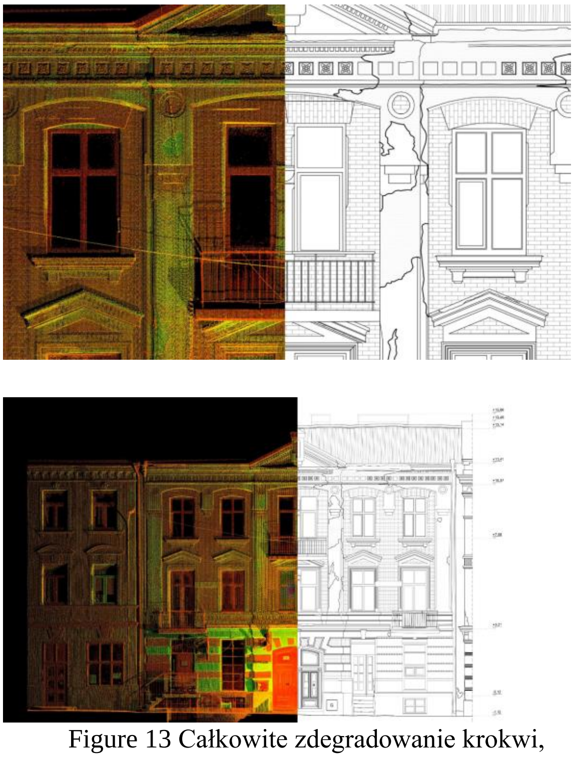


Figure 13 Całkowite zdegradowanie krokwi, widoczna próba częsciowej naprawy i wzmocnienia elementu

An alternative to point cloud scanning is simplified scanning, which is much faster and cheaper. Simplified scanning, including the technology of companies such as Matterport, and virtual tours, have an important application in the assessment of technical condition and protection of cultural heritage.

The first benefit of using simplified scanning is the ability to create precise 3D scans of objects. These scanners enable fast and accurate registration of the geometry and textures of the analyzed object. As a result, detailed and reliable data is obtained, which can be used to assess the technical condition and reconstruct historical elements.

Virtual tours are another tool that contributes to the assessment of technical condition and protection of cultural heritage. Thanks to virtual tours, users can move around the reconstructed virtual spaces, recreating their appearance, atmosphere and historical context. This allows not only for in-depth study of objects, but also for their preservation in a permanent form, in case of destruction or change of their original state.

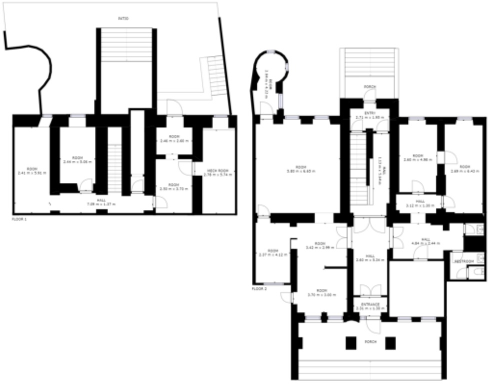


Figure 14 Automatycznie wygenerowane rzuty kondygnacji piwnicy i parteru w technologii MATTERPORT

Figure 15 Kład na płaszczyznę podłogi kondygnacji parteru w technologii MATTERPORT

Based on a virtual tour, which offers a spatial overview of the model of a historic object, it is possible to conduct a detailed geometric inventory of this object. This process involves the precise identification and measurement of all the essential elements of the object, such as walls, windows, doors or architectural ornaments. Using H-BIM technology, the geometric inventory can be carried out with great precision, allowing for the accurate representation of the object in the digital space. In this way, the virtual tour becomes not only a tool for exploring and presenting the object, but also for its analysis and assessment of its technical condition.

2.3.4. Orthophoto maps and views for graphical inventory of damages

The use of overlays on point cloud surfaces and non-perspective distortion models enables precise creation of graphic damage inventories, which significantly contributes to the improvement of the repair scope estimation process and costs associated with the renovation of construction objects.

The use of overlays, i.e. 3D scanning techniques based on point clouds, allows for the registration of accurate geometric data of the surfaces of damaged structures. This technology enables the transformation of a real construction object into a precise digital model, which in turn facilitates the analysis and identification of any damage and defects. Perspective distortion-free modeling provides reliable and accurate representation of the actual dimensions of damage.

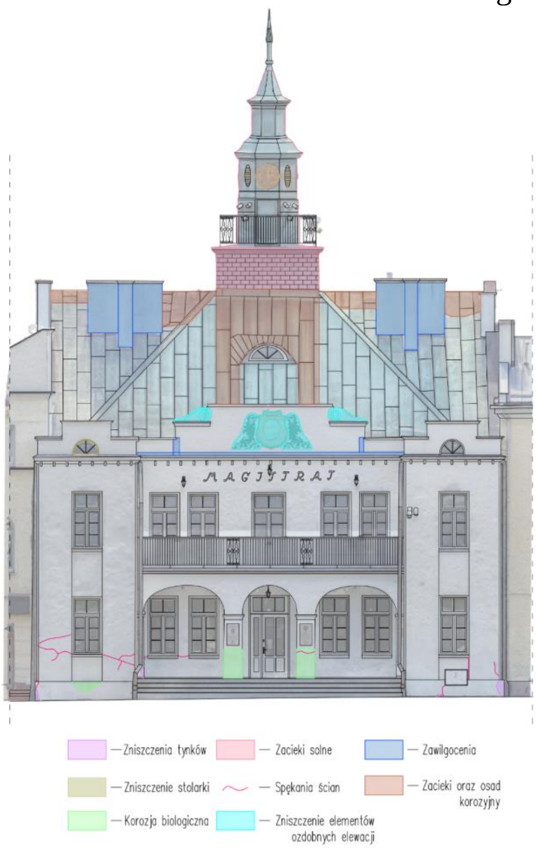


Figure 16 Inwentaryzacja graficzna uszkodzeń elewacji północno-zachodniej sporządzona na podstawie podkładu wykonanego metodą fotogrametrii

Figure 17 Inwentaryzacja graficzna uszkodzeń elewacji południowo-wschodniej sporządzona na podstawie podkładu wykonanego metodą fotogrametrii

A point cloud, generated during the scanning process of heritage objects, is a highly valuable data resource, which can be used regardless of having a full H-BIM model. These detailed three-dimensional representations (point clouds) of a heritage object allow for the identification and marking of elements with particular historical value, secondary elements, as well as damaged areas that may require repair or replacement.

The point cloud can serve as a platform for creating quick, yet detailed analyses of the object's condition. With it, it's possible to create an outline (substrate) on which different elements of the object can be marked, without the need to carry out complicated and time-consuming inventories using traditional methods.

Moreover, the point cloud is a dynamic tool that can be updated as new information becomes available, or when the state of the object changes. This enables the creation of updated outlines that accurately reflect the current state of the object, which is essential for effective conservation management, technical assessment, and maintaining its historical value.

Below are examples of using point clouds as substrates for marking historical and damaged elements.

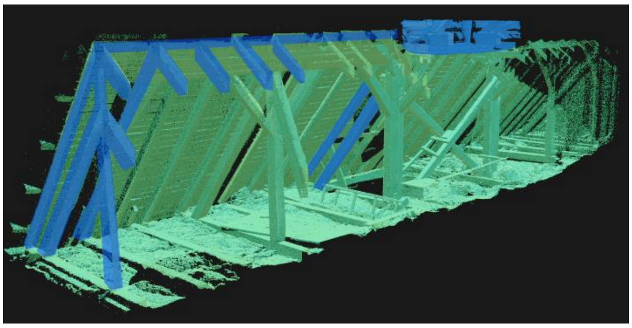


Figure 18 Analiza elementów więźby z podziałem na pierwotne i wtóre z wykorzystaniem chmury punktów

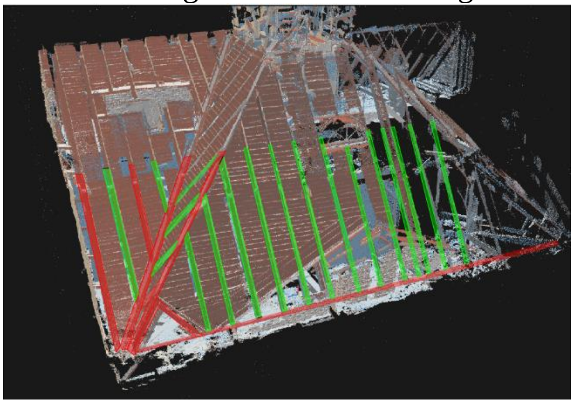


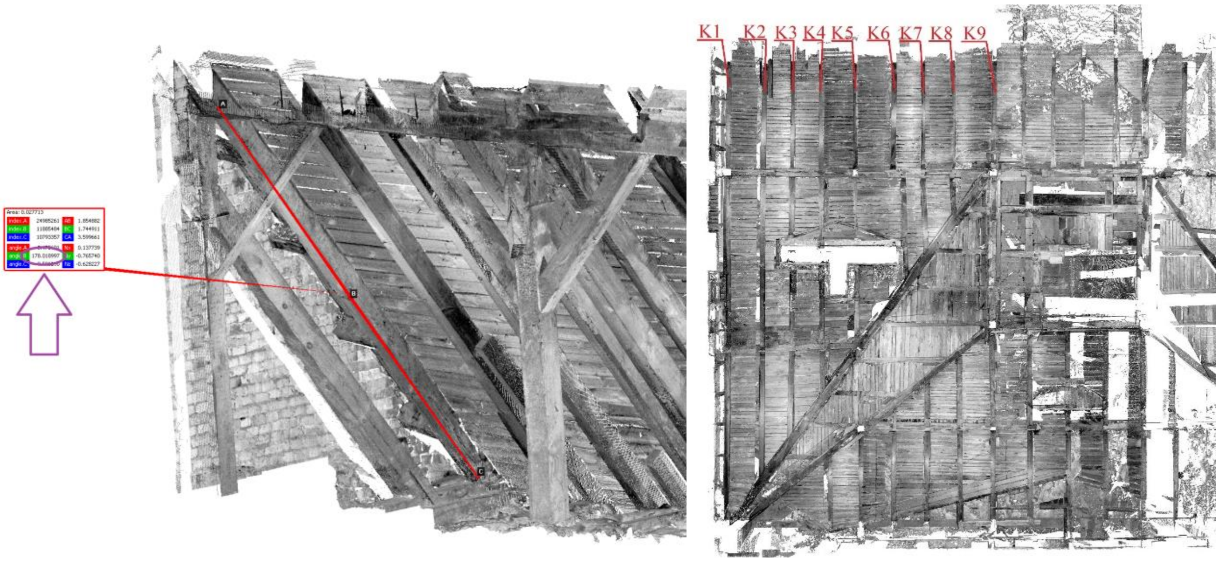
Figure 19 Wizualizacja graficzna występowania grzybów i zawilgocenia na więźby dachowej z wykorzystaniem chmury punktów

2.3.5. Testing the deflection of structural elements

The examination of deflections in structural elements of the roof truss using high-precision point clouds is an essential aspect in the analysis and assessment of technical condition.

The study of deflections of structural elements, in this case - the roof truss, is based on the geometric analysis of the point cloud made using the method of laser scanning with an average accuracy of ±1 mm. This analysis provides detailed data on the shape and geometry of the structural elements. Then, an analysis is conducted on selected elements, considering three co-planar points at the beginning, middle, and end of the element. These points are used to precisely determine geometric characteristics essential for determining the actual deflection of the element. Based on the collected data, the real deflection of the element is determined with an accuracy of up to 1 mm. This analysis allows for the assessment of rigidity, strength, and the identification of any irregularities and deformations. The deflection results of the elements are compared with the limit state of usability according to the PN-EN 1990:2004 "Basis of structural design" standard. This comparison enables the evaluation of whether a particular element meets safety and durability requirements.

Using high-precision point clouds to examine the deflections of structural elements of the roof truss allows for a precise analysis of the technical condition. This advanced measuring method provides essential information regarding deformations and strength of the elements, enabling early detection of potential problems and taking appropriate repair actions.



Rys. 2.1 Measurement of the deflection of a structural element

Below is a summary of the measurements of the actual deflection of selected structural elements of the roof truss based on the point cloud obtained by the method of station laser scanning. It was compared to the maximum deflection value determined from the formula for the limit state of usability.

Tab. Przykładowe zestawienie tabelaryczne zbadanych ugięć elementów krokwi.

No.	Element Name	Length [mm]	Deflection Angle [°]	Actual Deflection [mm]	Allowed Deflection [mm]	Excess Deflection [mm]
1	Rafter K1	4180	178,02	36	14	**22**
2	Rafter K2		177,72	42		**28**
3	Rafter K3		177,98	37		**23**
4	Rafter K4		177,53	45		**31**
5	Rafter K5		177,87	39		**25**
6	Rafter K6		178,68	24		**10**
7	Rafter K7		178,33	30		**16**
8	Rafter K8		177,47	46		**32**
9	Rafter K9		178,29	31		**17**

2.3.6. Testing of deformations on surfaces

Using the gathered spatial data in the form of point clouds, we can precisely analyze the shapes of objects that are represented by these clouds. XXX [13].

Analyzing the planes of roof surfaces using point clouds allows the use of color filters. The color is determined by the height of the points, making it easy to identify possible deformations. These deformations can indicate excessive bending of the structural elements of the roof truss, mechanical damage to the roof surfaces that might worsen over time.

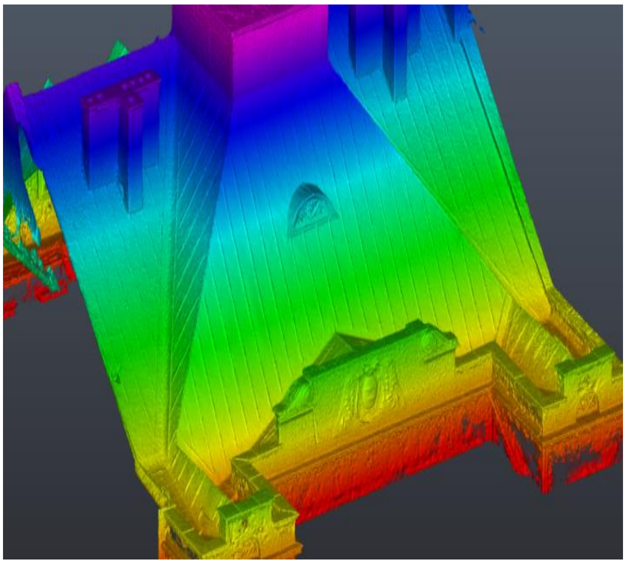


Figure 20 Analysis of a roof surface point cloud taken by the photogrammetry method focusing on the surface shape.

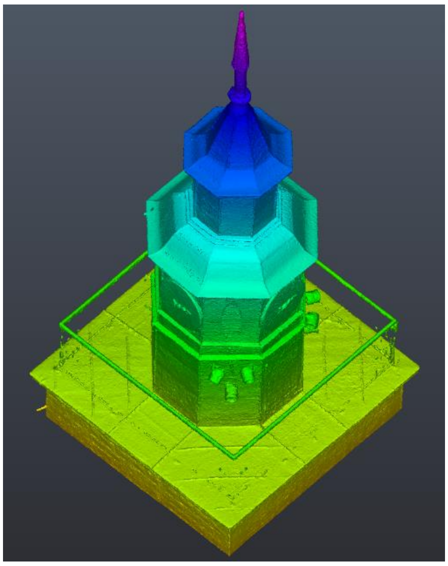


Figure 21 Analysis of a clock tower point cloud taken by the photogrammetry method focusing on the surface shape.

The point cloud can also help in identifying deformations of outer layers. These layers are often exposed to various damages, like cracks, erosion, or settlement. Thanks to the point cloud, it's possible to accurately understand the size and shape of these deformations, which allows precise diagnosis of the problem and planning appropriate repairs.

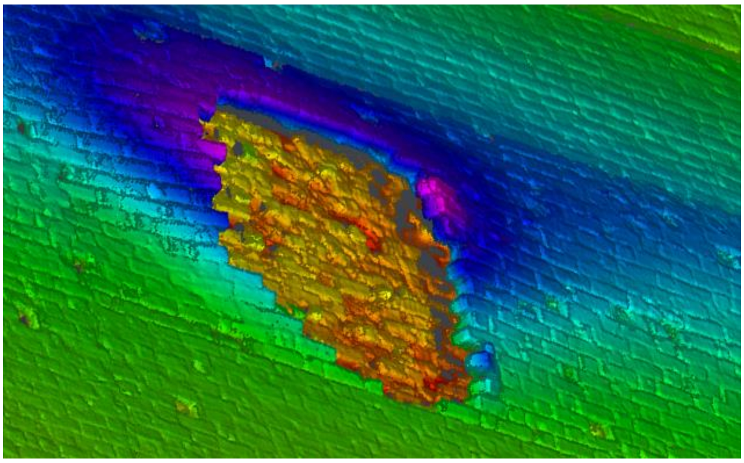


Figure 22 View of wall deformations based on the height analysis of the point cloud.

Figure 23 Damage to the protective wall of the Castle of the Dukes of Mazovia in Czersk. (photo by B. Szostak)

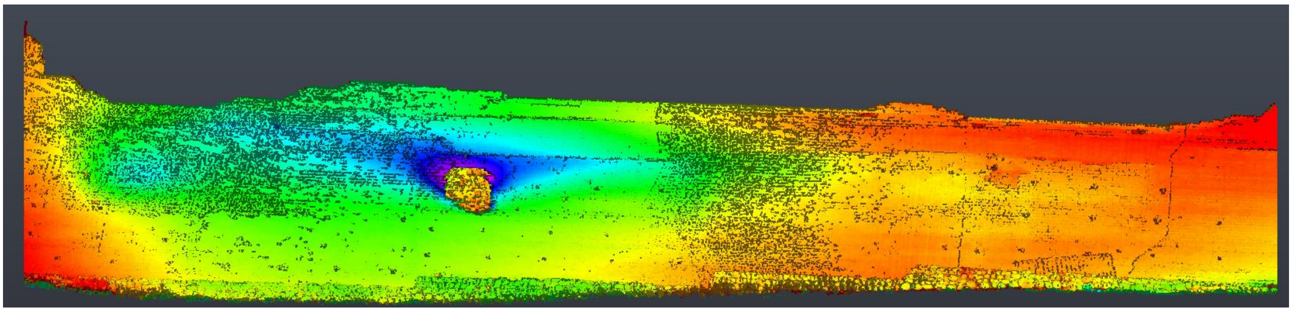


Figure 24 Full view of the deformations on the facade of the Castle of the Dukes of Mazovia in Czersk. Blue and green colors indicate deformation on the wall's plane, meaning its separation.

The conclusion is that using point clouds to analyze the shapes of objects allows for detecting and identifying different types of deformations. An example is the analysis of roof planes, where color filtering on a point cloud allows visually detecting potential issues. This advanced method of analysis can be applied in diagnosing the technical condition of buildings, allowing for quick and accurate detection of damage and taking the right repair actions.

2.4. Use of bim models and ifc parameters

Research in the field of information technology used in the preservation and management of historical buildings shows that the Building Information Modeling (BIM) method and the open standard (IFC) can play a key role in this process.

Using the BIM methodology for architectural heritage, known as Heritage Building Information Modeling (HBIM), has provided a lot of insights. It's important to note that parametric modeling, formulating databases, and managing information through BIM can be very beneficial for managing the historic built environment, especially during preservation, repair, and maintenance stages.

HBIM can also play a significant role in determining the best renovation solutions from proposed alternatives. It can integrate other often overlooked or unsystematically applied criteria, like compliance with preservation and restoration guidelines, economic aspects throughout the life cycle, including the energy efficiency of the final solution, and environmental aspects of a long-term heritage management plan.

HBIM includes the following BIM dimensions:

- Analytical study (3D), including establishing a geometric model;
- Historical evolution (4D), including a general assessment of the cultural significance of the property;
- Diagnosis (5D), including knowledge status, protection, potential preservation, and dissemination;
- Cultural context (6D), including environmental and territorial infrastructure; and related assets, preservation, and intervention;
- (7D), including a program for future research, protection, and conservation measures.

Using IFC parameters in Heritage BIM allows for dynamic and seamless information exchange. By applying an open standard file format for BIM representation, like IFC, geometric and non-geometric information can be stored and managed based on the IFC data schema, enhancing collaboration between people working on the model. They can use it in any BIM software and view it in any IFC browser.

In the context of managing heritage assets, this approach facilitates better integration of Facility Management (FM) information with every Heritage BIM object. The integrated Heritage BIM model is then placed in IFC, and the developed model is used to support renovation planning and FM activities.

FM-related information is added to heritage components, like walls, doors, windows, etc., to enhance their functionality and support various tasks. New parameters essential for heritage FM activities are defined as shared parameters since they can be exported to an external database management system.

With the developed system, tracking FM information and utilizing it for conservation tasks is now possible. The developed model has information about planned conservation for each heritage component, reminding managers to conduct detailed object assessments regardless of its conservation status.

Each component has a unique global identifier (GUID), tracking information about the element, and object-related information can be accessible and retrieved during FM tasks [13].

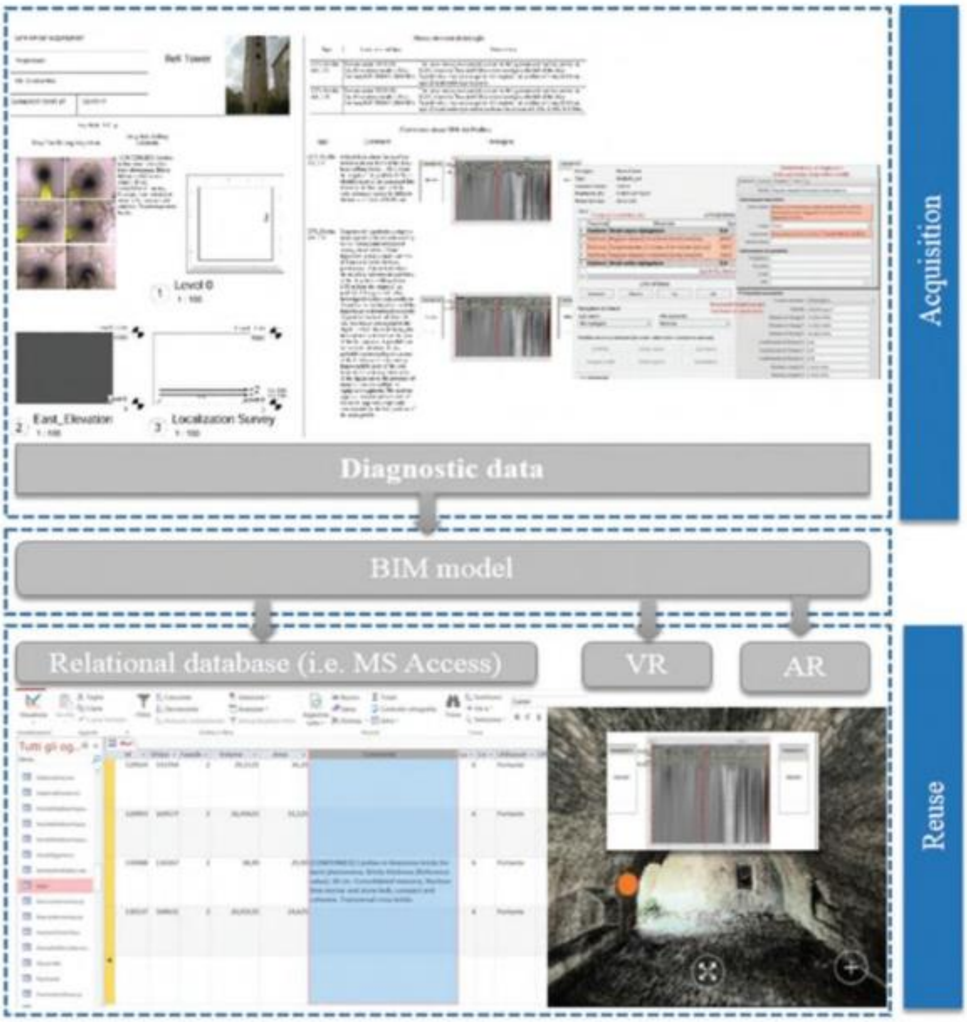


Figure 25 Schemat wykorzystania danych w modelowaniu H-BIM [14]

An example scheme for managing heritage objects using IFC involves several steps:

- Collecting relevant information important for renovation planning and asset management;
- Developing an integrated BIM model;
- Adding FM information to each heritage object in the BIM model and setting the integrated BIM model in IFC format;
- Using the developed model to support renovation planning and asset management activities.

Each unit is automatically assigned a unique global identifier (GUID), used for unique identification. Information related to the object can be accessed and retrieved during asset management tasks.

The integrated BIM model of heritage objects stores and manages geometric and non-geometric information based on the IFC data schema. This data can be displayed and accessed in any IFC browser. FM information is stored in IFC data under the IfcPropertySet group, and values are defined by the IfcPropertySingleValue. Each entity is automatically assigned a unique global identifier (GUID) for unique identification of each entity.

Previous studies on similar topics to conservation plans include data models for damage assessment or other structural or physical properties. Also, the use of HBIM for stratigraphic analysis was explored. Acierno et al. tried to expand the capabilities of standard HBIM models for objects with complex geometry. They emphasized the need for a methodology that combines IFC and heritage data models.

This research is not the first to suggest cultural heritage propositions for the IFC scheme: Diara and Rinaudo proposed informal additions to the scheme using CAD. Instead of including heritage elements in the ISO standard, they suggested methods for exchanging heritage information between different BIM software.

In conclusion, studies on the use of information technology in the preservation and management of historic sites highlight the significant role of the Building Information Modeling (BIM) method and the open standard (IFC). This method offers several opportunities, such as parametric modeling, information management, and formulating databases, beneficial for managing historical sites. Furthermore, HBIM helps determine the most efficient renovation solutions from available alternatives. Using the open IFC standard allows for efficient data exchange between different platforms, minimizing the risk of information loss.

Here are examples of buildings where digitization and HBIM-related work was done:

- Sagrada Familia Case [19]: For the Sagrada Familia in Barcelona, Spain, a combination of laser scanning and photogrammetry was used. Laser scanners captured the building's overall geometry, while photogrammetry detailed intricate sculptures and facades. These data were merged into a comprehensive 3D model of the building. Using both laser scanning and photogrammetry captured high-detail, including intricate geometries and precise design elements. This digitization process assisted ongoing construction and conservation efforts in the Sagrada, which has been under construction for over a century.

Figure 26 Scanning methods of Sagrada Familia [15]

- Egyptian Temples at Abu Simbel Case [20]: For the temples at Abu Simbel in Egypt, a mix of ground-based laser scanning and aerial photogrammetry was applied. Ground-based scanning created a detailed 3D model of the temple interiors and exteriors, while aerial photogrammetry captured the surrounding landscape and the site's overall context. These 3D models were used for detailed study and documentation of the temples, providing valuable information for conservation efforts.

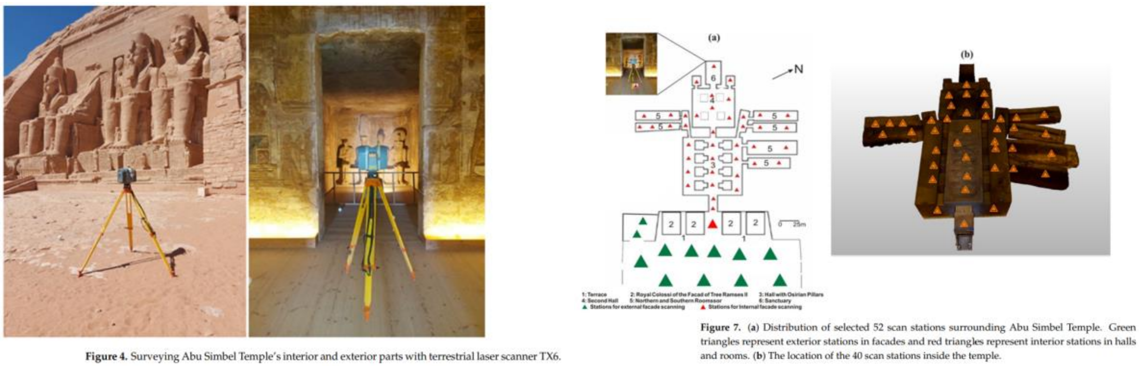


Figure 27 Use of scanning methods in the Abu Simbel temples [16]

- Authors of the article [21] identified challenges with digitizing historic buildings having complex (non-parametric) geometries. These features make conventional digitization methods imprecise and time-consuming. As a result, remote sensing technologies, like 3D laser scanning and photogrammetry, were adopted. These save fieldwork time and are highly accurate in recording buildings' irregular geometries. The authors focused on the challenge of effectively transforming remote sensing data into intelligent parametric models, which remains an unsolved problem. They developed an HBIM (Historic Building Information Modeling) model of historical landmarks using 3D laser scanning and photogrammetry. Their work is illustrated with a case study: Engine House Paços Reais in Lisbon.

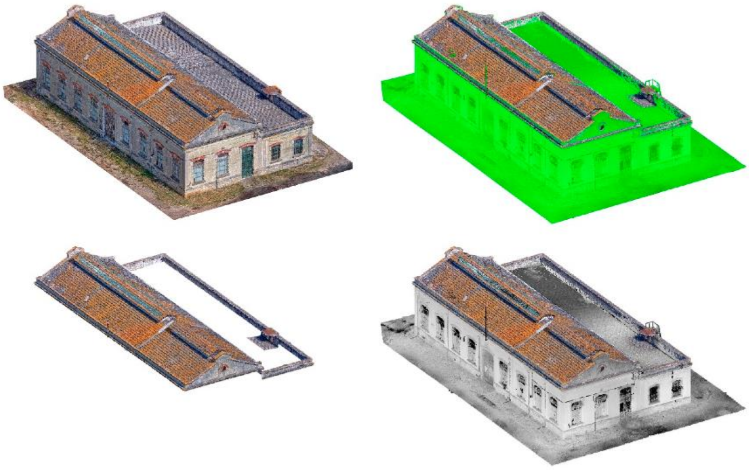


Figure 28 Engine House Paços Reais in Lisbon [12][17]

- 3D Scanning of Notre-Dame Cathedral by Andrew Tallon was incredibly detailed and technologically advanced. Tallon recorded data from over 50 locations inside and around the cathedral, resulting in a staggering billion data points. Each scan began by mounting a laser on a tripod and placing it inside the object. The laser swept the area in all directions, and when hitting a surface, the beam reflected back, registering the exact location and surface of every element. All these points formed a detailed image. From these millions of points, a three-dimensional image of the cathedral was produced. The resulting images were incredibly accurate; if the scanning was done correctly, as Tallon stated, it should be accurate to within 5 millimeters. This monumental task contributed significantly to our understanding of this historic structure and might serve as a foundation for its future restoration [12] [13].

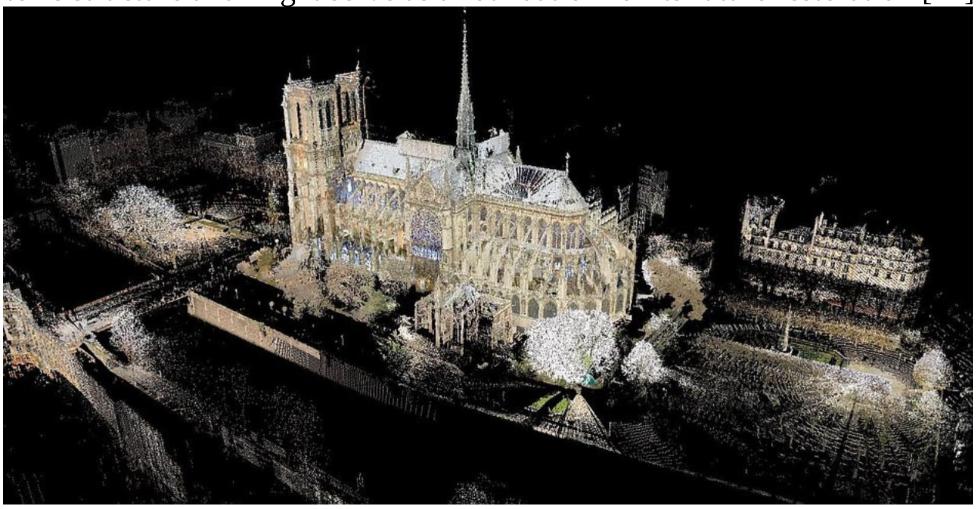


Figure 29 3D model of Notre Dame Cathedral [12]

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3. Heritage BIM as a tool for heritage management and preservation

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The use of BIM to existing buildings, with particular reference to the cultural heritage of the individual Countries, is a necessity linked to the building market, to the awarding of public contracts, to which is added, not least, the need to use design tools that are able to manage timing and actors (stakeholders) involved in the restoration project, so that the optimization of the same restoration design process is achieved only starting from a deep knowledge of the existing building.

This knowledge is aimed at the creation of a model. This model becomes increasingly effective and "eloquent" as the knowledge process deepens.

Indeed, it must be remembered that the description of an existing building cannot refer to standard data. “In BCH (Built Cultural Heritage) the construction systems (as material, technologies, way to conceive the construction) do not refer to standards and, at the moment, they are not defined with unambiguous codified names. The knowledge of architectural heritage (not necessarily ancient or “monumental”) is based on the specific study of the material features, acquired with methodological and destructive techniques (destructive tests) and/or non-destructive ones (NDT)”[1].

In the knowledge, that it is based on different typologies of data (in terms of sizes, nature and so on) related to the description of existing building and built environment, as an ensemble of buildings (as historic centers), in general, is not made by standard data. The data are not standardized because they are referred to historic period when standard was not existing any more and, plus, because, even if we are mor consciousness of their making (according to, for instance, specific building laws) from the theoretical point of view, it is impossible, immediately, if the construction is, exactly, the mirror of what is prescribed by law or regulation.

Instead, it is possible to standardize the knowledge procedure and process, following the diagnosis project based on geometrical survey, historical research of the construction phases of the building and destructive and (preferable) non-destructive tests for the description of the material composition of the building.

The purpose of the research, summarized in this didactic instrument, is to make the transfer in the BIM process the data for establishing the right procedure for the use of BIM methodology in the management of the existing building, with special attention to the architectural heritage expression of legacy and culture of a Country.

- Definitions

The meanings suggested for the following nouns.

Model: a simple description of a system or process that can be used in calculations or predictions of what might happen [https://dictionary.cambridge.org/it/dizionario/inglese/model. Accessed 31/07/2023].

Knowledge: understanding of or information about a subject that you get by experience or study, either known by one person or by people generally [https://dictionary.cambridge.org/it/dizionario/inglese/knowledge. Accessed 31/07/2023].

Survey: a description of the whole of a subject; an examination of the structure of a building by a specially trained person; the measuring and recording of the details of an area of land. [https://dictionary.cambridge.org/it/dizionario/inglese/survey. Accessed 31/07/2023].

Data: information collected for use; [https://dictionary.cambridge.org/it/dizionario/inglese/data. Accessed 31/07/2023]; the basically knowledge collected and connected with each building element in order to describe it in a useful way for restoration.

Parameter: a set of facts or a fixed limit that establishes or limits how something can or must happen or be done [https://dictionary.cambridge.org/it/dizionario/inglese/parameter. Accessed 31/07/2023].

Information: Information about someone or something consists of facts about them

[1] [N. Lombardini and L. Cantini, Non-Standardized Data In The Bim Process. The Management Of Construction Systems Data In The Cultural Heritage Conservation, 3rd International Conference on Protection Of Historical Constructions Lisbon, Portugal, 12 – 15 July, 2017, p. 1-12, quotation at p. 1].

[https://dictionary.cambridge.org/it/dizionario/inglese/information. Accessed 31/07/2023]

"What is the difference between data and information? Data can be numbers, words, graphics, photographs, sounds, videos. The datum is a codified result, a representation of information, in itself it is not information: it is a fact, a measure of a fact which, in order to become information, must be contextualized, compared, interpreted and made accessible to different targets. Man provides a meaning to the data and therefore interprets it. The data and its interpretation become information"[2].

Conservation :

WHAT IS THE CONSERVATION? WHAT THE CONSERVATION MEAN? WHY I HAVE TO CONSERVE?

Italian refers to *Conservazione*, that it is possible to translate Conservation that is the same in English or Preservation.

According to Feilden "Conservation is the action taken to prevent decay and manage to those who use and look at historic buildings with wonder the artistic and human messages that such buildings possess. The minimum effective action is always the best; if possible, the action should be reversible and not prejudice possible future interventions. The basis of historic building conservation is established by legislation through listing and scheduling buildings and ruins, through regular inspections and documentation, and through town planning and conservative action."37F[3]

It is possible define Conservation as an action to maintain the current condition of the object from the physical (we cannot consider the assertion: from the appearance) point of view.

Why it is necessary to conserve the material of the cultural heritage?

in the material, in its processing, in its use, in the way of work it is possible to find the traces of the civilization of one people: they are the witnesses of the culture of a people (in the material itself – the building material changes in order to the geographical changings; the changes of the material requests different way to work it).

"…What copying can there be of surfaces that have been worn half an inch down?

The whole finish of the work was in the half inch that is gone; if you attempt to restore that finish, you do it conjecturally; if you copy what is left, granting fidelity to be possible, (and what care, or watchfulness, or cost can secure it,) how is the new work better than the old? …"

By Ruskin, *The seven lamps of architecture*, aphorism 31, p. 195 edition 1989.

"….The material used in the work of art carries the message of the image and it does so in the two ways which can be defined as structure and appearance…."

By Brandi, Theory of restoration, p. 51

Which are the relationships between the conservation of the material of the object and the shape of it from aesthetic point of view?

Which are the relationships between aesthetic shape and typology of the building?

"…We now return to the problem of keeping or removing additions, bearing in mind that not only a ruin is involved. It could be (and frequently is), the case that additions have been made to works of art that could recover their original oneness (and not just their potential oneness), if, wherever is possible, the additions where removed. It should be realised that, by viewing the problem from the aesthetic standpoint, the historical approach is overset, in that its focus is on preserving the additions. In the case for the artistic nature of work of art, the call is for removal. So, as possible conflict emerges with the conservation requirements advanced by the historical case….."

By Cesare Brandi, Theory of restoration, p. 73

This approach influences not only the idea of what the culture wants to transmit to the future but also:

- The characteristic of the architectural and urban shape of the building and of the city.
- The construction labour market

[2] *"La comunicazione di pubblica utilità*", edited by S. Rolando, Milano: Franco Angeli, 2004, p. 356 [translated by N. Lombardini].

[3] http://www.icomos.org/en/charters-and-texts http://www.getty.edu/conservation/ publications_resources/research_resources/charters.html http://www.beniculturali.it/mibac/export/MiBAC/sito-MiBAC/MenuPrincipale/ Normativa/index.html; Feilden, op. cit., p. 3.

- The culture of restoration, in general.
- The project of restoration.

Conservation follows two purposes:

- To preserve the cultural heritage
- To start an eco-friendly action that means to preserve the material.

Conservation of the building materials implies:

- To know very well the shape and the geometry of the structures and of the building
- To know very well the construction materials and the construction techniques (of the present and of the past).
- To know very well the decay of material and structures
- To know very well the causes of the material and structure damages
- To know very well the restoration and consolidation techniques that can conserve "in situ" the historical materials and structures
- To think about the adaptive re-use.

The conservation project has developed strategies, instruments and knowledge (diagnostic in conservation and restoration).

It is necessary do not forget that the building material disposal has a huge social cost and it is not sustainable38F[4].

3.1. BIM: Characteristics and potentialities

The BIM methodology has been increasingly confirmed as one of the main tools for the building design process. Its centrality is due to the development of both the techniques and the instruments that are necessary for accomplish a digital modeling (i.e. the implementation of the BIM authoring software, the higher accuracy of the digital survey tools) and to the legal requirement of this process for the design of new buildings, which has been introduced gradually during last years[5].

The BIM process represents an operative tool that has been increasingly widespread within the architectural studios and the public administration offices, both for the design of new buildings and for the management of the existing ones. The adoption of this work-methodology will be exploited further in the

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[4] In Italy there are no specific Guidelines for the Conservation Project of the monument.

The conservation of architecture (and cultural heritage in general) goes through the Government (MiBACt – Ministry of Cultural Heritage and Tourism- and MIUR – Ministry of Education and University) and the regulations of the City Council. The architect (not the engineering) is the responsible of the restoration project of the monuments. The architect identifies the aim of the project and conservation (respect of the historical material as the respect of the building history) is the one that Politecnico di Milano teaches.

University trains the architect and the public administration, City Council (for its competences – respect of the City's regulations) and MiBAC, through offices as Soprintendenza per i beni architettonici e per il paesaggio supervises the restoration project and the restoration work.

[5] In Italy, the application of BIM for public procurements is required not only for the design of new constructions, but also for the design of public buildings and for the management of built environment. The full implementation of the legal adoption of this requirement is expected by January 2025, but it has been gradually entered into force already starting from 2016. "*The decree of 2 August 2021, n. 312 amends the previous ministerial decree 560/2017 on BIM and introduces a different timing on the mandatory use of electronic modelling methods and tools for construction and infrastructure in public procurement and, in particular, provides reward scores for the use of BIM in public procurement financed by the PNRR and the PNC. The mandatory nature of the BIM is imposed according to the following schedule:* 1 January 2022 for new construction works and interventions on existing buildings, with the exception of ordinary maintenance works for a basic tender amount equal to or greater than 15 million euros; 1 January 2023 for new construction works, and interventions on existing buildings, with the exception of ordinary and extraordinary maintenance works for an amount based on the tender equal to or greater than the threshold referred to in article 35 of the public procurement code (5,350,000 euros for public works contracts and concessions); 1 January 2025 for new construction works, and interventions on existing buildings, with the exception of ordinary and extraordinary maintenance works for a basic tender amount equal to or greater than 1 million euros" Translated by N. Lombardini [https://bim.acca.it/obbligo-bim-appalti-pubblici-dal-2022-al-2025/. Accessed 31/07/2023]

future, due both to the legal requirements and to the improvement of the accuracy and of the efficiency of the digital survey techniques.

Being aware of this exploitation, the professionals and the technicians involved in the building process should have a deep comprehension of the main characteristics of this tool, regarding both which could be its potentialities and its main issues. This kind of knowledge will interest not only the nowadays and future professionals. For this reason, teaching the use and the potentialities of BIM students of Architecture and Engineering is fundamental and, for this reason, urgent.

The use of BIM methodology in a building design process allows not only to have a digital model of a building, but also to approach the project making available all the data useful to establish the knowledge for the building.

According to BIM methodology, the data representing and describing the building can be drawn on a graphic and parametric base. One of the strengths of this process is because the digital model is a set of data linked to a set of single virtual objects. Each of these data describes different features and/or properties of each building element. In case of an existing object, as a specific environment or a building, even if an architectural heritage, the use of BIM methodology facilitates the creation of a virtual model that is a repository of data with which it is possible to offer the description of the object: the project of the way to collect data and to link data to the virtual model build the "information model" of the building or of the environment.

Indeed, the BIM model can give further data in addition to the graphic ones, since it is made of single elements that correspond to a precise building category, such as walls, slabs, foundations, roofs, openings, etc. Each of these objects is made, in turn, by single elements representing the items of the "stratigraphy" of the building object and different data can be associated to each element.

The data can define the distinctive characteristics of the object, such as geometric data, materials, physical properties, construction systems, and structures. Moreover, these data can be stored according to a useful procedure for ensuring further interventions over time.

These data can be stored in a double mode: they can be registered directly available as properties of the object, or they can be stored as *metadata*[6] in a virtual environment (i.e. a cloud) that is associated to the BIM model. Some examples of metadata are, f.i., data that cannot be directly parametrized[7], such as technical archival drawings, text documents, pictures, sketches, movies, ecc..

It is necessary to consider that the total amount of details useful for determining and modelling the object is not the same during the whole design process. On the contrary, any change is depending on the design phase of the building.

Thus, it is very important to differentiate which are the meanings of the two nouns as "data"[8] and as "information", as well as which is the importance of the concept of "workflow" and of its organization.

[6] Metadata: *information that is given to describe or help you use other information*. Online Cambridge Dictionary [https://dictionary.cambridge.org/it/dizionario/inglese/metadata. Accessed 31/07/2023].

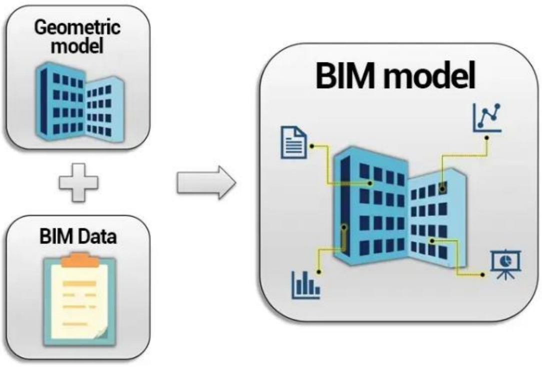
[7] Parameterization: *to describe or characterize in terms of a parameter*. Online Collins Dictionary. [https://www.collinsdictionary.com/it/dizionario/inglese/parameterize. Accessed 31/07/2023].

Parameter: Parameters are factors or limits which affect the way that something can be done or made. Online Collins Dictionary. [https://www.collinsdictionary.com/it/dizionario/inglese/parameter. Accessed 31/07/2023]. See the Chapter "Definitions".

[8] Data: facts or numbers, collected to be examined and considered and used to help decision-making, or information in an electronic form that can be stored and used by a computer. Online Cambridge Dictionary [Accessed 31/07/2023]; Information: Information consists of the facts and figures that are stored and used by a computer program. Online Collins Dictionary. [https://www.collinsdictionary.com/it/dizionario/inglese/information. Accessed 31/07/2023]. See the chapter DEFINITION, too.

"BIM is a workflow that supports the creation of intelligent data that can be used throughout the entire lifecycle of a project"[9]. BIM is not just a software it is a database able to transform the data in information through a model that makes up the project as a whole (Fig. 1 and Fig. 2).

Figure 30 Contents | Geometry and BIM Data. BIM Data: what are they, what are they used for and



why are they so important? July 15, 2022 [https://biblus.accasoftware.com/en/bim-data-what-are-they-what-are-they-used-for-and-why-are-they-so-important/. Accessed 31/07/2023].

In order to better understand it is possible, also, to make reference to the legislation: in Italy, the main reference is the UNI 11337 series, which correspond to the international standard UNI EN ISO 19650[10]. These technical official documents define precisely which are the categories within whom the knowledge about a building should be classified and organized. Indeed, these categories are arranged hierarchically within systems of classes and sub-classes with a semantic logic. Each class and/or sub-classes contains data related the single objects. Moreover, single classes are subdivided in "data", that are the base-unit of the system, and in "information", that represent a set of "data" aimed to a specific meaning.

Concerning the given "information", it should be correctly set starting from the initial design

Figure 31 Types of BIM Data. BIM Data: what are they, what are they used for and why are they so

[9] "BIM workflow: scopri cos'è e perché fa la differenza", https://bim.acca.it/bim-workflow-cosa-e-perche-fa-la-differenza/ [Accessed 31/07/2023]. Translated by N. Lombardini.

[10] UNI: Ente Nazionale Italiano di Unificazione (Institute for National Standard); ISO: International Organization for Standardization; EN is referring that the standard has been accepted by the European Community.

[https://www.ingenio-web.it/articoli/standard-bim-il-mondo-dopo-la-iso-19650/. Accessed 31/07/2023].

"International standards, which are developed and published by ISO (International Organization for Standardization), can be adopted at national level by each member state on a voluntary basis. In Italy they are recognizable by the acronyms UNI ISO; The European standards, which are elaborated by the CEN (European Committee for Standardization) in the three recognized languages, English, French and German. Each member state is obliged to transpose them and withdraw the regulations in force, typically national, in contrast to them. For example, they recognize themselves as UNI EN; National standards are developed by the recognized national body. In Italy, the UNI, and the related federated bodies, and the CEI are responsible for writing standards. They have value on the national territory and are written in the mother tongue of each country". Cavallo D., De Gregorio M., Mirarchi C., A. Pavan, "Standard BIM, il mondo dopo la ISO 19650", in https://www.ingenio-web.it/articoli/standard-bim-il-mondo-dopo-la-iso-19650/ [Accessed 31/07/2023] Translated by N. Lombardini.

Moreover: Aggregation of facts is called data which has some value and size. For any operation to be done, data should be processed into information by the help of knowledge discovery process which is used for finding information which should be … , Sinkon Nayak, Mahendra Kumar Gourisaria, Manjusha Pandey, Siddharth Swarup Rautaray, *Recent Dimensions of Data Science: A Survey, in Advances in Data and Information Sciences*, Proceedings of ICDIS 2019

pages 465-476, p. 466; *From Data and Information Analysis to Knowledge Engineering*, Proceedings of the 29th Annual Conference of the Gesellschaft für Klassifikation e.V., University of Magdeburg, March 9-11, 2005, edited by M. Spiliopoulou, R. Kruse, C. Borgelt, A. Nürnberger, W. Gaul, Springer, 2005.

important? July 15, 2022 [https://biblus.accasoftware.com/en/bim-data-what-are-they-what-are-they-used-for-and-why-are-they-so-important/. Accessed 31/07/2023].

Phase of the BIM model, since it corresponds to the general organization of the data that will be then used during the whole management of the BIM process: thus, the more structured the flow will be, the more precise and clear will be also the representation of the acquired knowledge about the building.

According to the UNI 11337, the BIM informative process for the buildings deals also with their intangible aspects, and it differentiates the operative model according to diverse design phases and stages that represent the building "life-cycle". Indeed, BIM model should collect the design steps, representing all of them: starting from the ideation and from the following feasibility analysis until the development of the executive project and the management phase of the building, that also involved the maintenance process.

3.2. The application of BIM to the built environment and to the architectural heritage

Despite if BIM is generally applied to the design and the management of new constructions, it can be applied also to the works that deal with the existing buildings. Italian legislation requires, as it has been said, the use of BIM for the intervention on the existing buildings starting from 01st January 2025, while it recommends its adoption, without specific requirements, for the management of the maintenance works, both the ordinary and the extraordinary ones.

In 2010/2011 the interest and the research about the use of BIM methodology in the conservation and management of architectural heritage and, more general, existing building was not so developed and the bibliography was the witness of this phenomenon.

While it is not mandatory, the use of BIM for the management of the built environment presents a set of advantages. This is also the case for the management of the maintenance works on the built heritage. As known, when we talk about new buildings, the maintenance phase deals with the period that follow the end of their construction. If BIM process has been adopted for manage the whole construction process, starting from the ideation until the handling of the construction-site of the building, this means that it can be then easily applied also to the management of the building. This phase is part of the whole BIM process, and it is inserted inside a well-established "workflow," according to a specific organization of both data and information, as well as to a controlled accessibility to them and to a sharing modality of the data that has been clearly defined during the previous phases.

For the same reason, BIM process can be applied to the management of the existing buildings too, for instance for managing the maintenance works on the historical buildings, or others interventions that modify the building, such as conservation interventions and/or other works that can change the structural scheme, the presence of inadequate systems, the functional layout or the use of the building.

Thus, the BIM process for the existing buildings can be usefully applied to the management of the maintenance works on the buildings, both the ordinary and the extraordinary ones. The adoption of BIM agrees to have a digital tool that can easily store not only the data related to the maintenance intervention, but also the ones concerning the building in its material consistence and history. This process lets:

- The possibility to organize the data about the maintenance intervention in an ordered way, according to a pre-codified hierarchic scheme. This scheme will connect the maintenance data to the digital elements of the building, having a complete archive of not only the present interventions, but also of the ones accomplished in the past.
- The possibility to store the data concerning the building in the same digital archive where also the data related to the works of maintenance are kept. This will help the management of the activities, meaning that the stakeholders, and owners too, can have an easy access to the data related to the maintenance intervention.
- The possibility to use a codified a uniform method for the storage and for the scheduling of the maintenance activities. This will facilitate not only the ability to find useful data concerning the history of the maintenance of the building, but it will also allow to compare the data and the efficacy of the adopted interventions.

The BIM, in all the cases described above, ought to be able to offer the correct information model.

For this reason, it become very important the phase of the acquisition of the data and their management inside the BIM software, offering to the stakeholder a right information model. The collection of the available geometric data permits to manage the data inside the BIM software create an accurate digital model, while storing the data about the materials and the decay of different elements of the building will permit to better manage the future interventions. Thus, this set of knowledge concerns structural, architectural, plant and decorative data. Acquiring this knowledge is important since it permits to the technicians and/or to the stakeholders that are in charge of the management of any kind of historical building and of the schedule and the design of the activities to maintain a complete awareness of the required interventions, as well as where and when they will be necessary.

As a consequence of this connection between the conservation (also concerning the planned one) and the historic buildings (i.e. one building listed as built heritage), a specific information model, fitted to the foreseen goals, is conceived. Thus, the organization of the available data characterizing the building, as well as how they are connected to the virtual BIM model, are very important. In any case, the methodology according to which the analysis is developed, and the data are collected in an information model can become a reference for future analysis, constituting the base for the creation of a further new BIM models that will deal with historic buildings and with their management[11].

3.2.1. Main features of the BIM model for the existing buildings

In the case of buildings belonging to the built heritage, the application of the BIM process deals with its survey and knowledge. This means that it is necessary not only to create a three-dimensional model able to provide a representation of the real/existing building (as built?) but, also, to indicate all the available additional data (such as parameters and/or metadata) related to its construction elements. The result of the process should be able to give the most complete amount of information in a clear way: this information is becoming from the planned data connection and liking.

Greatest attention must necessarily be paid to the phase of the acquisition of data and to their representations. For this reason, it is constantly necessary to think carefully:

- the typology of necessary data;
- the survey of the data;
- how to organize the data of the individual elements that are part of the BIM model;
- what information these must be able to represent;
- which should be the aspect of the data (i.e. metadata, links, hyperlinks, alphanumeric codes, etc.);
- which should be the requirements for the access to the information. It is therefore necessary to design the structure of the BIM model starting from the beginning of its preparation. The knowledge that can be interrogated by consulting the data or attributes (in BIM language) that are linked to the single elements should be organized in a well-defined structure, so that:
    - the way to access the flow of information will be clear;
    - it will be easy to update the data without repetition;
    - it will be possible to ensure that the data can be consulted in an interoperable manner by all the operators that are involved in the management process of the historic building: from the owners to the administrators and to the technicians.

During the survey of the data, it is necessary to consider:

- which type of knowledge (which level of its depth) can be achieved;
- if the level corresponds to the most suitable one;
- what is the goal that could be reached through this knowledge;
- how to reach the data those are the core of the knowledge;
    - which is the best approach for making the data available in the BIM, in order to develop the information model.

[11] The operative methodology that should be followed for applying the BIM workflow to an historic building includes:
- the purposes of investigation;
- the main critical characteristics that are connected to the acquisition of the knowledge of an historic building;
- the choice of the more appropriate techniques for the survey;
- the choice of the tools that are required for the acquisition of the data relating to the built object (both the graphic and the non-graphic ones).

The operative methodology has been the subject of the outputs IO1 - IO2 - IO3, where it has been already explained.

3.2.2. BIM as an innovative tool for the management of Built Heritage

As it has been already said, BIM is therefore an operative tool that can offer many advantages even during the management process of the built environment, also considering the management of the maintenance phase of both the historic and the monumental buildings. This is true only if the whole workflow is designed *a priori*, according to a precise organizational logic

that can codify hierarchically all the work-phases, from the phase of the acquisition of data and

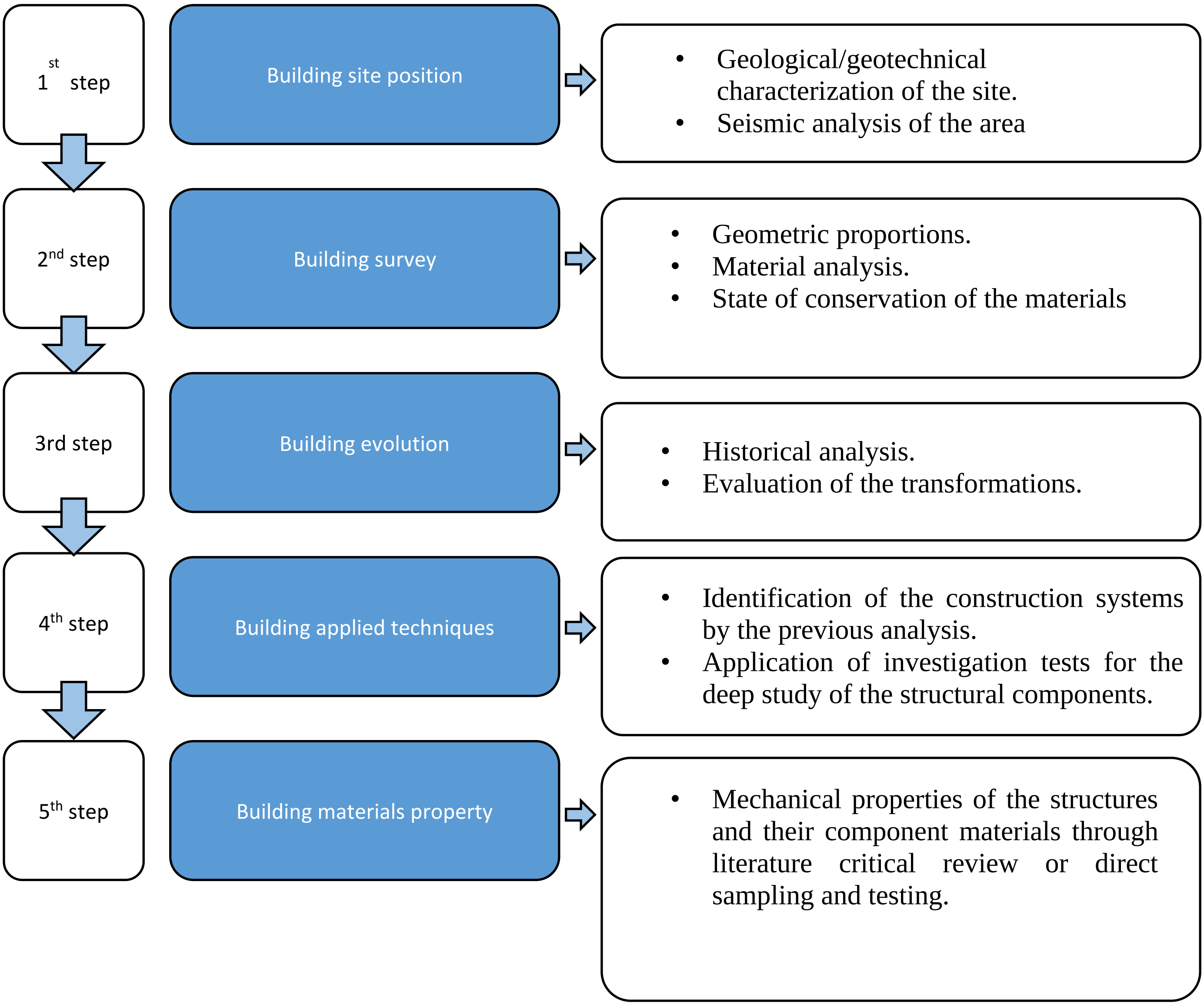


Figure 32 : Definition of the knowledge phases and the corresponding knowledge levels. (From Lombardini and Cantini, 2017).

knowledge, to the ones of their representation and of the storage of the new data, achieved during the maintenance of the building.

The ability to share data of different characteristics and nature, is due by the way to link the data in the BIM software.

As it is well known, when a project must deal with an historic building not all the data are directly available. It is possible to describe the building only through a good diagnostic process, with which it is possible to make a cognitive model of the good.

3.2.3. From the instrument to the methodology: knowledge, data, workflow

If correctly planned, the BIM working method can be applied to make the information model of existing buildings or built environment. The design phases of the BIM model include:

- the survey;
- the definition of the most appropriate representation method of the components of the three-dimensional model,
- the punctual description of some individual elements, in order to ensure, where it is necessary, an adequate level of reliability of both the graphic details and the data that are connected to the single objects.

The transposition of the knowledge that is inferable from the material data of the existing building to the virtual one has a role of great importance and is the essence of information modeling.

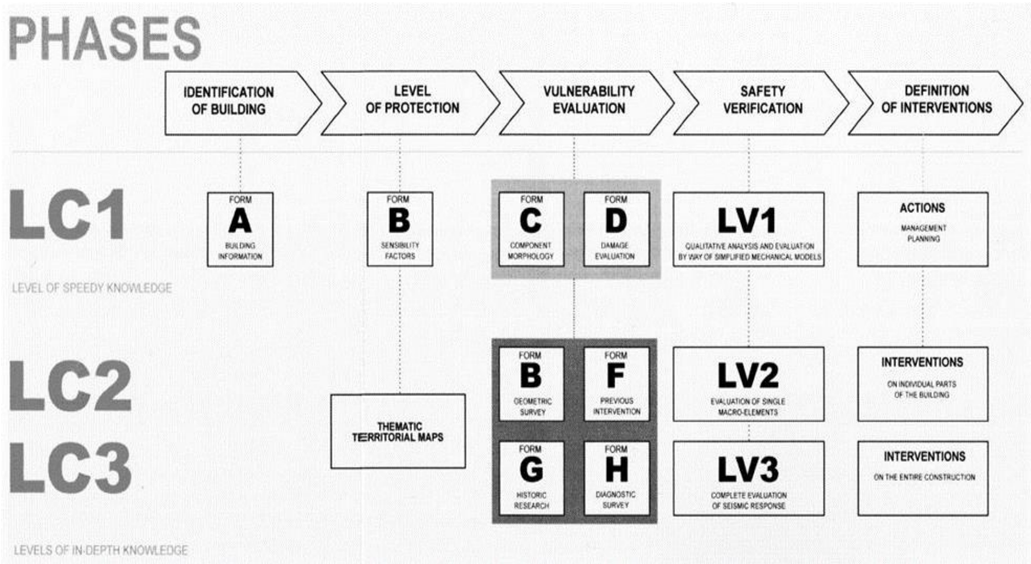


Figure 33 : Relationship between the survey forms, level of knowledge and level of verification as defined in the Guidelines (from *"Guidelines for evaluation and mitigation of seismic risk to cultural heritage, Gangemi Editore, Roma, 2007, p. 64*).

Regarding the existing buildings, the survey through the application of advanced techniques (f.i. laser scanner tools and photogrammetry) permit to create the 3D model with different levels of accuracy, according to the needs of the project. In recent years, the survey technologies have seen a continuous improvement, which has allowed to have tools able to acquire images more and more faithful to the reality, able to show 3D representations that are displayed with ever greater detail even within the BIM modeling software.

What the 3D model survey cannot show is the core of the structure, especially the masonries and the reinforced concrete cement ones.

It is important to know the detail of the masonry's elements (stones, bricks, mortars, etc.) and their dimensions or the dimensions and distribution of the iron bars in the concrete cement structures.

The achieving of the data missing by the geometric survey and simple pictures, because invisible, is fundamental as it is important to know the state of conservation of the single elements of the building and of the hole building

For properly manage the planned maintenance and, more generally, the conservation process of a historic building, since it allows to identify:

- the different textures coexisting in the building,
- the construction techniques,
- the possible degradation/alteration/decay/feilures of materials and structures.

The principal result coming out from the process of acquisition of the knowledge that is inferable from the study and from the survey of the building is a representative description (interpretation) of the building that must be returned by the information model. (Figg. 5, 6, 7)

The main important data useful to describe the existing building are connected with the following questions:

- Which are the materials of the building?
- Which are the construction techniques?
- If there is any degradation, where and which were the past phenomena and which were their causes?
- How the structural system works?
- Did any change in the use and/or in the layout of the building happen over time?

The process of virtual modellization of historic buildings requires a high fidelity of representation regarding the built elements, which cannot therefore be standardized. On the contrary, it is possible, as it was already said, the standardization of the knowledge, through the collection of data available in the archives, deducible from the geometric surveys and using diagnostic procedures and tools. (Fig. 8)

To improve, develop and have under control the survey of the data useful to implement the project of knowledge, the use of technical worksheets, allowing the punctual evaluation of the characteristics of the buildings, seems to be a valid solution.

These worksheets are able to seek the expected results regarding both the accuracy and the reliability of the data, as well as the possibility of operating their future enactment and adequate interoperability capacity.

An example of the application of some technical worksheets has been tested positively during the acquisition of the data that were necessary for modeling the "*Colonia Elioterapica/Daily Summer Camp*" in Legnano (Milan). The historic building, which has been designed by BBPR Studio and was built around 1938, is the case study that has been selected for the HBIM project by the Italian group. A more accurate description of both contents and purposes of these technical worksheets has been presented in the Intellectual Output IO3.

3.3. Sheets for the technical conditions assessment

If the building belongs to the existing built heritage, the virtual BIM model should be able to represent not only its external shape, whose three-dimensional image was acquired through the execution of a laser scanner survey and of photogrammetry, but also the knowledge that can be inferred from the study of the building. This knowledge should therefore include a range of various information, such as:

- geometric data;
- historical information, including both the ones relating to the history of the building and therefore to the different construction phases;
- the materials and the construction systems;
- the level and type of degradation/alteration/decay/feilures;
- the existence of past restorations.

This knowledge is necessary to allow an adequate understanding both of the historical-construction and of the material nature of the entire building in its changes along the time. Aiming a “good” knowledge of the building, it is necessary to introduce:

- the study of the existing documentary sources;
  - the inquiry of the archival material (i.e. project drawings, photographs, documentation relating to past interventions);
  - a careful observation of the existing situation;
  - the execution of diagnostic surveys.

To be effective and to exploit its full potential, the use of a BIM process for built heritage should be able to represent this additional data, starting with the interrogation of the three-dimensional BIM model. The additional data should be visualized as properties and data connected to the single elements of the modelled building (i.e. wall, column, window, etc.).

A good test has been carried out for the Italian case study that has been analysed during the HBIM project. The BIM modeling process of this building started through the geometric survey of its parts using advanced survey techniques as the photogrammetry and the 3D survey by laser-scanner. The virtual 3D model was created, and the additional available data, such as images and/ or copies of text documents have been then associated to some of the individual elements of the model.

For the case study of the *Colonia Elioterapica*, different models of technical sheets were used. These forms, called "Sheets for the technical conditions assessment", let be possible to acquire specific information in relation both to the morphological and to the structural aspects of the inquired building.

They are composed of 12 different models, prepared according to the type of data that they allow to acquire. These models are divided in the following categories:

- Complex and state of art.
- Master data.
- Morphological – structural characteristics.
- Foundations.
- Vertical structures.
- Horizontal structures.
- Stairs – ramps – elevators – freight elevators.
- Roof.
- Temporary or definitive elements for structural improvements.
- Decorations.
- Openings.
- Installation and facilities.

Each of the models includes a series of data related to one of the 12 categories, and it can be filled according to levels of an increasing depth of knowledge. Each model follows a common approach, and it presents some recurring fields in which a series of unambiguous data can be indicated. (Fig. 3)

The presence of such data makes it easier to identify the building to which they relate. Moreover, in the perspective of BIM's logic, the different codified fields of the technical sheets permit also to more easily interpolate the data that are inserted in the different tabs.

These "common" data are for example:

- the code assigned to the building,
- the historical period of reference of the characteristic/part of the detected object,
- a field related to the insertion of additional notes and/or drawings or freehand sketches.

3.4. Discussion

The Heritage BIM project allowed to experiment the application of a working method based on the BIM modeling process. The process has been applied to some case studies of built heritage, to verify the potential deriving from the use of this instrument and to highlight the main critical elements.

The application of this work methodology to some existing buildings has proved how the adoption of BIM process can be a fully functional tool for the management of the distinct phases of maintenance of the existing buildings. Dealing with a monumental building, the modeling of the corresponding virtual object must be carried out very carefully, paying attention to achieve a detailed level of the virtual representation, which can correctly describe the current shape of the building.

The modeling of an existing building also puts the problem of knowledge, which plays a primary role in the correct choice of which could be the most suitable representation method for the building. Namely, unlike the case of the modeling process that is adopted for a new building whose data are already included in the starting design phases, the data that are referred to an existing building often must be acquired at the same time as the virtual model. Thus, when the data are not present in the archives or they are incomplete, it is also necessary to acquire them through specific investigations, which include both visual analysis of the building and diagnostic investigations (better if no-destructive ones).

It is therefore clear that the process that leads to the knowledge of the building must follow a well-ordered working methodology, which allows to acquire and to organize the collected documentations and data in a clear way, according to the logic of the BIM process. Following such methodology will also allow to enter the data correctly, according to a setting that consents an easy access, consultation, sharing and updating.

The correct setting of both the workflow and the insertion of data can exploit the potential offered by the application of BIM to the management of the maintenance phase of historical buildings. Among these potentialities there is certainly the better ability to share the data of the historical-construction knowledge among all the actors that are involved in the management of the maintenance process: thus, involving not only the technicians, but also the owners and/or the administrators that are responsible for the conservation of the building.

The 3D model created based on the laser-scanner survey is only one of the applications allowed by BIM, and the visualization of the virtual model is not the only way through which to obtain information relative to the building.

Thanks to the technical innovation in digital survey, the three-dimensional model is able to represent with higher precision and details the existing building, but it can represent only the characteristics of the surfaces and of the shape of the building. On the contrary, concerning the knowledge of specific material characteristics, it is necessary to consult the data that the parameters linked to the single 3D-modeled objects can give. The parameters must therefore be carefully selected when the information is entered into the BIM software during the modeling phase, in order that the virtual model can be able to return detailed and comprehensible information to the users.

3.4.1. Main potentialities for the built heritage

Among the potentialities offered by the application of BIM methodology to the conservation and the management of built heritage, there are:

- The possibility to update information on both the history of the building and the restoration and/or maintenance works that are carried out.
- The ability to keep a copy of previous interventions so you can not only compare them but also be able to know more easily the maintenance history of the building.
- The possibility to make available the data relating to the different categories of intervention that has been performed: from those connected to the maintenance of the surfaces /finishes to those related to the management of the plants and/or to the structural and/or conservative interventions.
- The recognizability of data in a clear and immediate way, which is made possible by the correct organization of specialized work environments within the same set for the building.
- The possibility of being able to consult the data in a clear and immediate way, and to share them with the other actors/subjects/technicians (stakeholders) with different specializations that are involved in the maintenance activities.
- The possibility to carry out the scheduling of the future inspections and/or the maintenance interventions, on the basis of the frequency and the results derived from the previous interventions, which have been recorded among the data of the virtual BIM model.

As a result, both the availability, the updating and the awareness of this type of data allows an improvement in the efficiency of the future planning of the interventions that are necessary for the management of the existing building. Maintenance can be more easily planned on a regular basis, and it can also be understood with greater awareness what have been the previous interventions on decays, their causes, and their location.

3.4.2. Main issues and reflections

The use of BIM process for the management of built heritage allows to obtain multiple advantages: not only for the design of the restoration works, but also for the ordinary management of the property, including planned conservation and minor maintenance works. Nevertheless, if neither the workflow, nor the information that are stored inside the BIM software, have been correctly set, it won't be possible to take full advantage of the potentialities offered by this tool. At the same manner, even the process of knowledge of the building is not completely understood. The management of information and the knowledge process related to an historical building therefore assumes a fundamental importance.

In addition, it must always be clearly remembered that each building represents a singular case, which is unique and non-repeatable due to the presence of an exclusive combination of uses, construction techniques, materials, degradation, repairs and interventions, or other changes suffered by the building in the past. This is true not only concerning the changes related to the use, but also concerning the material and/or structural changes, as well as the evolution of the construction techniques that have accompanied them. For this reason, the insertion of data within the BIM environment must take place consciously: the information management process must therefore be carefully planned so that the data entered in the software are complete, and that the information are then uniquely identifiable, easy to access and implementable without giving rise to repetition.

In this sense, the application of technical sheets such as the "Sheets for the technical conditions assessment" that have been tested for the case study of the "Colonia Elioterapica/Daily Summer Camp" of Legnano (MI) proved to be effective as a reference model for the activity of both selecting and cataloguing data related to a historical building. Moreover, the technical sheets have also guaranteed the possibility to deepen further the information of each listed category, according to the available level of knowledge.

This resource, thanks to the exhaustiveness of the categories of data that it allows to collect and to the logical ordering through which the information is structured, well corresponds to the operating logic of BIM process. Indeed, the structure of the technical sheets lets to reach progressive levels of knowledge in a deductive manner, from the acquisition of general information to more detailed information. The BIM software consent to manage information relating to a historical building through the initial setting of a well-ordered "workflow", gradually implemented according to the respect of hierarchically linked categories.

Regarding potential future developments of the methodology that has been adopted for inquiring the available knowledge on the building characteristics, the "Sheets for the technical conditions assessment" could be still implemented. In this sense, the information that are contained in the technical sheets should be managed directly by consulting the *Property tables* that are linked to the single elements of the virtual model.

Implementing this solution, also the reference of the data to the corresponding building elements will appear more immediate. Furthermore, it will permit to compare data between similar elements or within the same element in a more evident way, and it will reduce the "risk of loss" of the acquired knowledge.

3.5. Conclusions: towards the correct management of a new tool for the preservation of Built Heritage

The BIM logic offers several advantages when it is applied to the built heritage. Indeed, the possibility to consult BIM model of an existing building allows to easily manage the restoration, conservation and maintenance of the building.

Nevertheless, applying BIM process to heritage buildings does not consist in the simple acquisition of data from a survey performed with laser scanner techniques and in their representation through a digital model. Indeed, this procedure won't be sufficient to complete the knowledge that is normally required to the technicians and/or to the other main subjects that are normally in charge of the maintenance and of the preservation of the heritage.

In order to take full advantage of the benefits and the potentialities offered by the application of BIM process to the management of the built heritage, we must firstly ask ourselves what type of knowledge we want to pursue and how complete should be the level of the information that is possible to detect from both surveys and historical/diagnostic investigation, that should then be represented in the BIM virtual model.

BIM is a tool that represents a built object, whatever if it is a new building or an existing one. Therefore, the process of acquiring both the building data and knowledge appears to be of primary importance and this awareness must be adequately transmitted, both to the users of the BIM model, and to the technicians and designers (not only the present professionals but also the ones of tomorrow) who will deal with the creation, the management and the implementation of the model, as well as with the maintenance works of the building.

In order to be able to ensure a correct use of the advantages and of the resources that are related to the adoption of the BIM modeling techniques, it must always be clearly defined what will be the purpose of the data acquisition and what benefit will be achieved with the knowledge related to a historical building. Moreover, it must be equally clear how the correct management of the information represents also the best operational methodology to achieve the next implementation of the BIM model.

In the case of architectural heritage, the aim that should be pursued by a virtual modeling always remains the understanding of the built object in its material and construction complexity. The built heritage represents a set of peculiar objects, which are different one from each other and that present specific and unique characteristics, generated by the building transformations that have undergone in the past.

The main goal of the process of knowledge of a building that belongs to the architectural heritage is then the ability to properly and adequately conserve the building, respecting its historical-construction characteristics and preserving at the same time its complexity.

BIM should not represent the ultimate purpose of a project, with the main risk of confusing the virtual model only as one of the results of the design process. On the contrary, it should be remembered that BIM should be considered mainly as a useful tool through which today it is still possible, and necessary, to wonder why a building should be preserved, what information can be identified in it, what information can/should be transferred to future generations, and what is the best and the most effective way to pursue this aim.

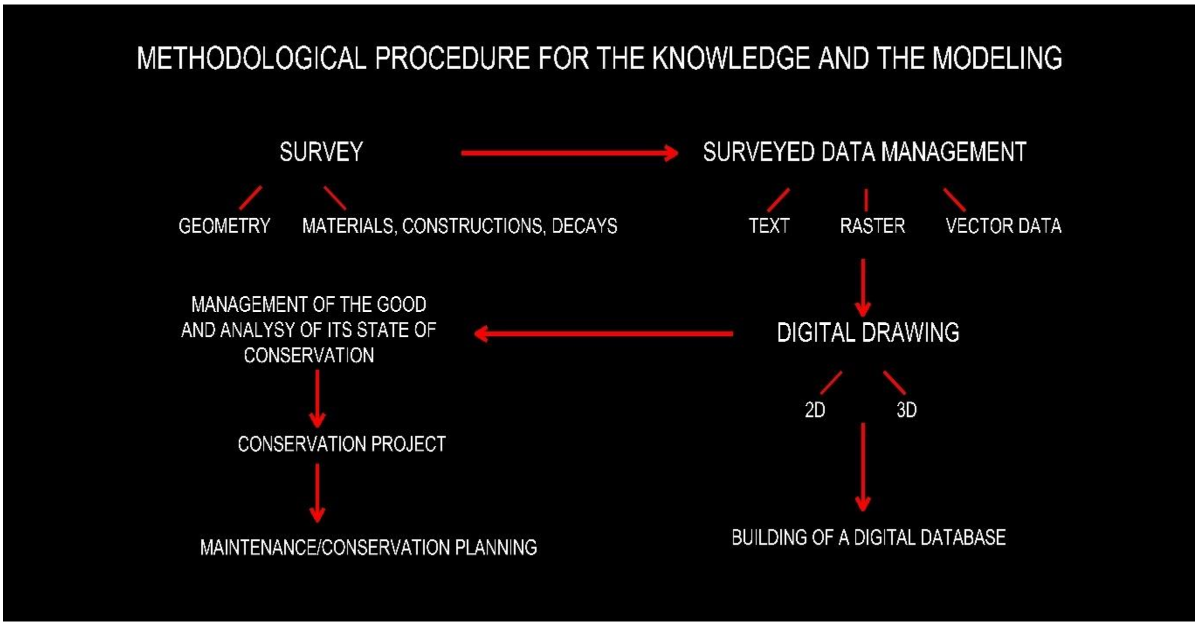


Figure 34 - Achille, C., Lombardini, N., Valentini, M. (2013).
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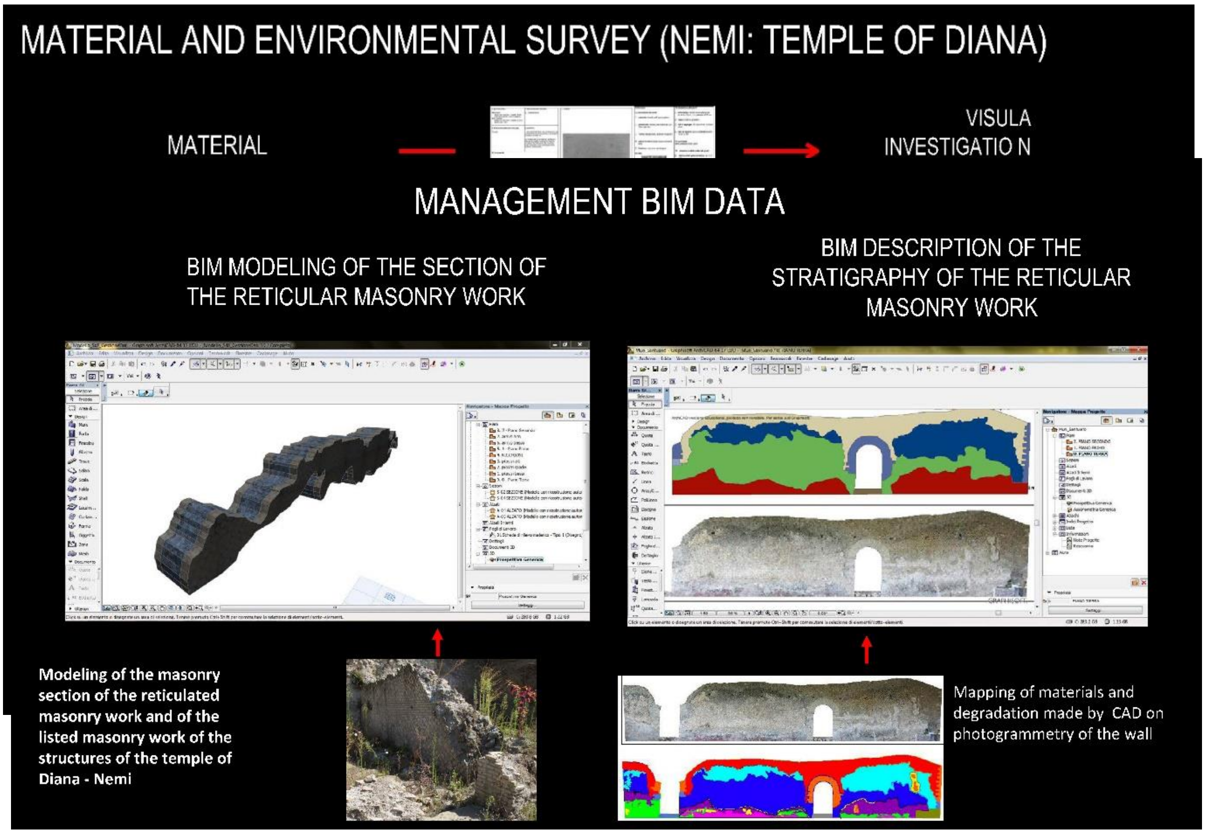

Fig. 8- Achille, C., Lombardini, N., Valentini, M. (2013).
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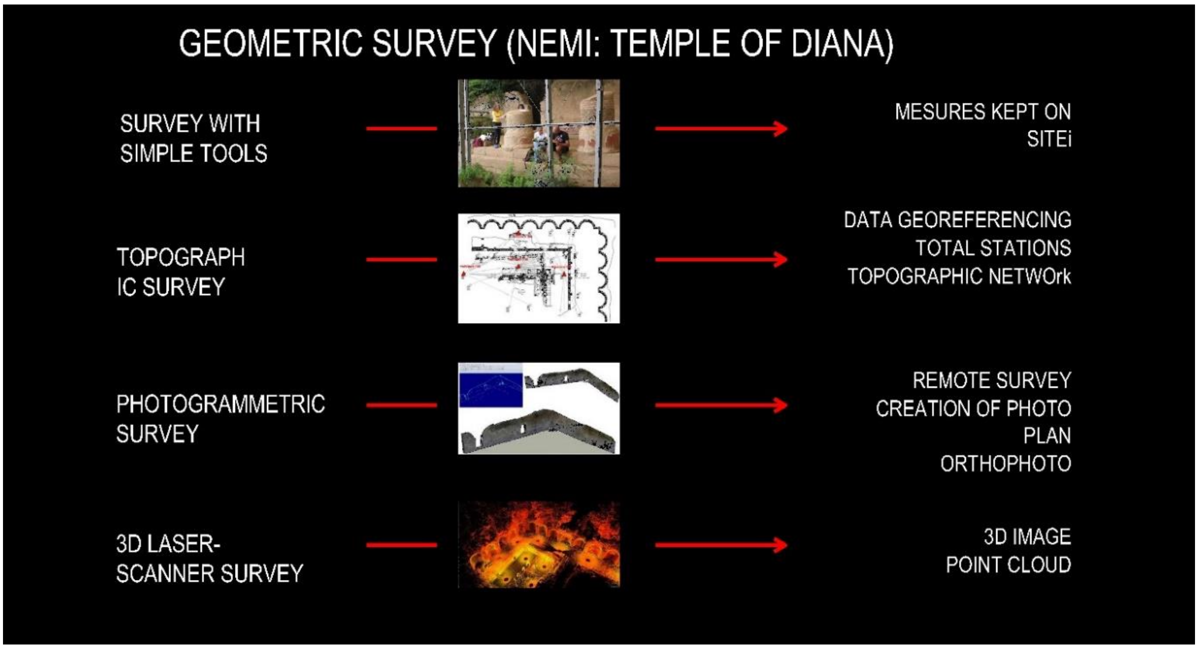

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4. Heritage BIM in Practice

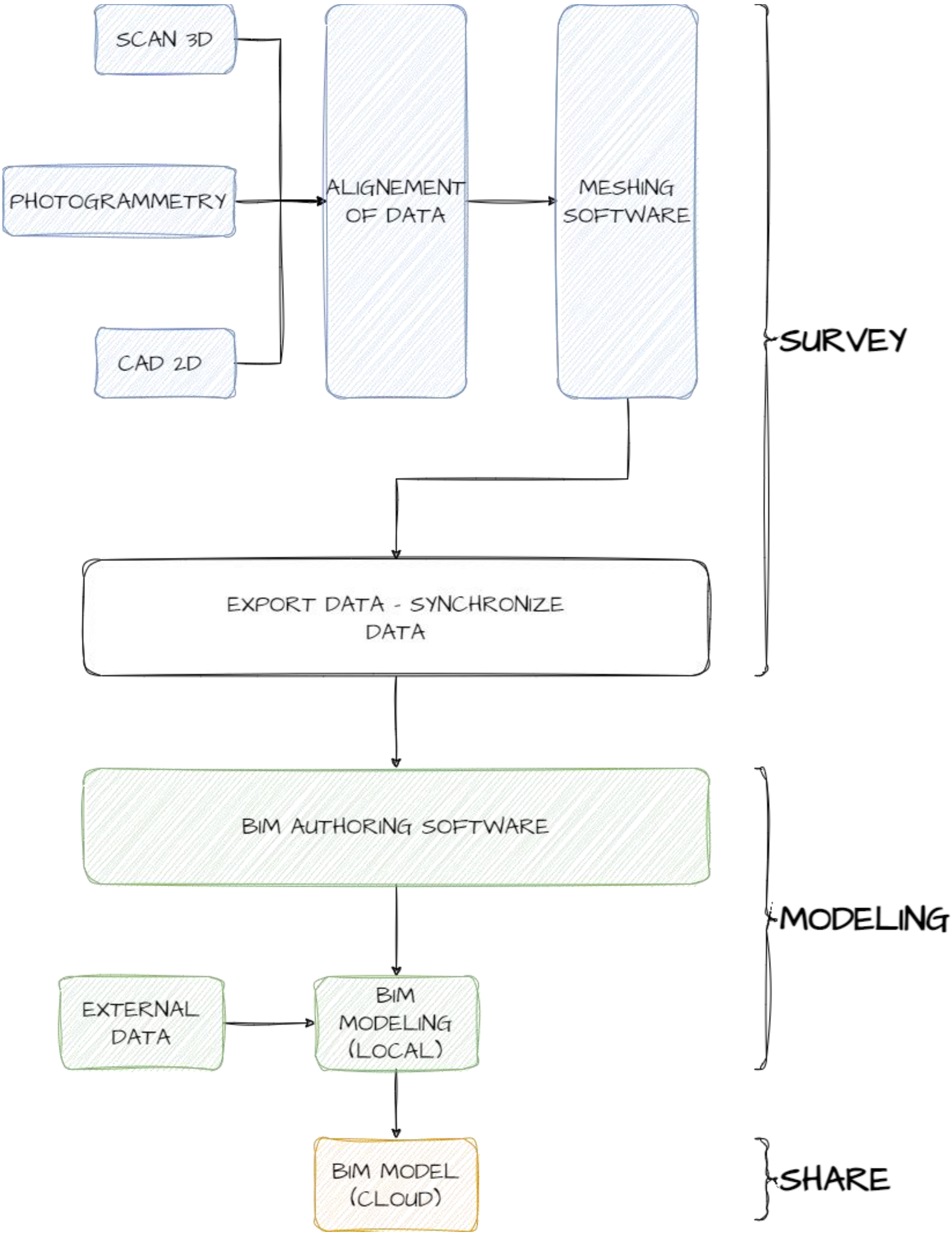

Image 1 - general workflow from Survey to sharing Data

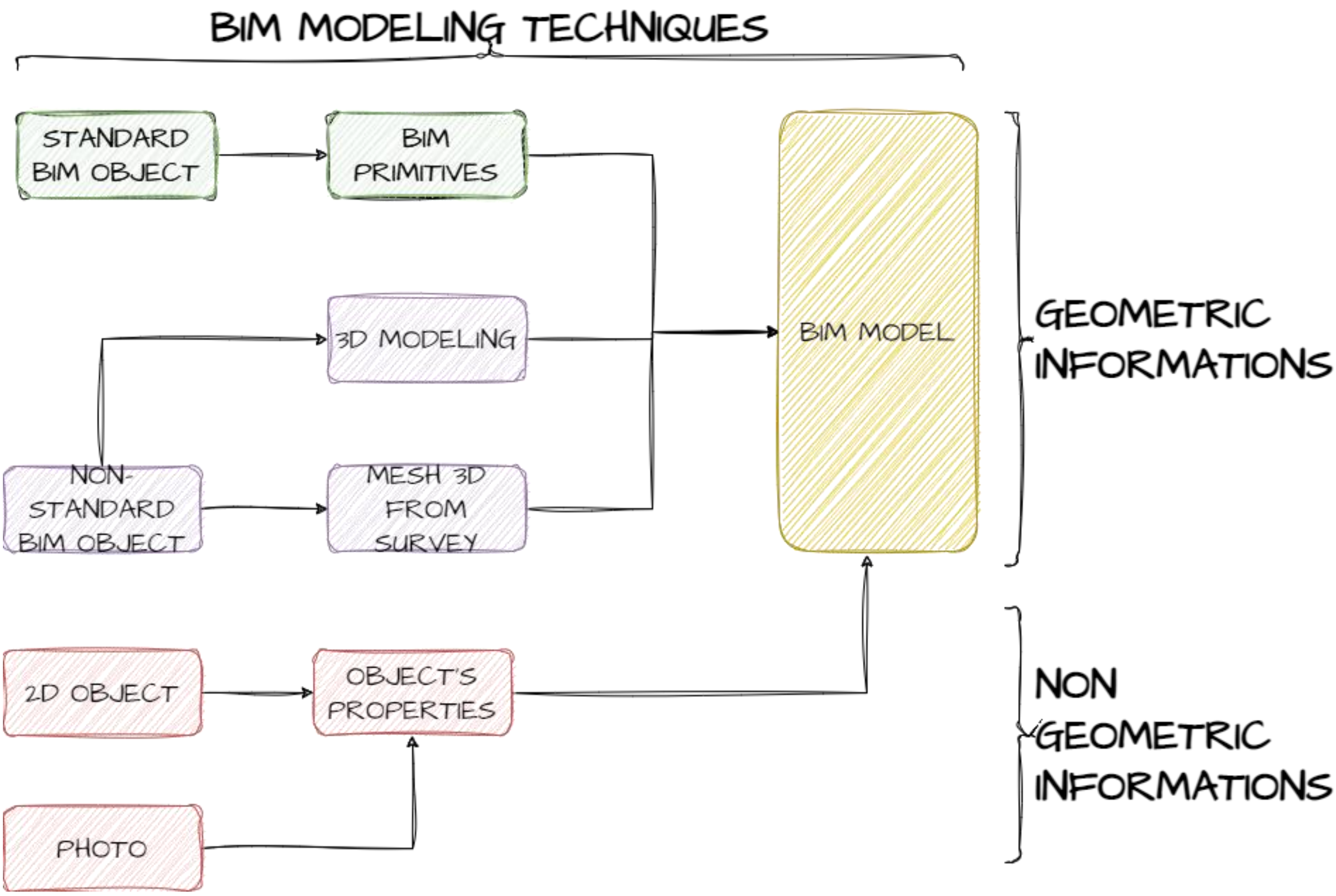

Image 2 – HBIM modeling techinques

4.1. BIM modeling techniques

When it comes to modeling a structure with BIM authoring software, the first thing you need to consider is the ultimate purpose of this work.

Image 1)

The balance is fundamental for the usability of the BIM model through both "standalone" BIM authoring software and through online data sharing environments.

Downstream of this first step, we must also consider the degree of graphic definition that we want to achieve in the objects present in the building.

We remind you that standard construction elements can be managed with a minimum meshing, thus allowing you to have a light BIM model.

It is clear, however, that in the case of non-standard elements (decorations, moldings, friezes and artistic works more generally) we must use a "mixed" modeling technique: on the one hand to carry out photogrammetric and 3D laser surveys that allow to obtain a faithful result, on the other a series of cleaning and simplification operations of the mesh to be able to then manage it easily once positioned in the general BIM model.

4.2. From survey to BIM model (Image 2)

The product of a relief is generally characterized by:

A. a point cloud resulting from a 3D laser scan;

B. a 3D mesh (with or without textures) derived from a series of photos or videos and processed by specific 3D photogrammetry software;

C. 2D CAD drawings;

D. 2D scans of paper documents.

4.2.1. First step

In the cases mentioned, the first activity to be carried out concerns the selection of the information that is considered most useful for the BIM modeling of the building.

What do you mean? Let's analyze case by case to better understand the steps:

A. a point cloud resulting from a 3D laser scan.

Laser scanning allows to have a particularly detailed result of the building considered.

1. For the purposes of BIM modeling, it is good to reason according to typical sections of the building.
2. We import the most significant horizontal and vertical sections of the point cloud of the detected building into the BIM Authoring software. This is possible in most software in this category.
   a) Purpose of this activity:
      i. be able to have a clearer and simplified view of the progress of the structures that make up the building.
      ii. Model with precision by exploiting the snap points offered by imported scans, thus making the final result more faithful to the original.

1. Once the modeling of the interior spaces has been defined, we use the same technique for the correction and modeling of the elevations.

   a. PROS
      i. Possibility to extract as many sections as desired according to the complexity of the building to be modeled;
      ii. Use of 3D points imported from the point cloud as snap vector elements, thus being able to offer maximum precision in modeling;
   b. CONS
      i. Weighting of the BIM model, due to the amount of 3D points imported;
   c. TIPS
      i. Previously study the model detected with laser instruments, to understand where to extract the most significant sections;

A. mesh 3D (with or without textures) (Image 4)

A 3D mesh is useful for the purposes of an HBIM model especially in the case of surfaces or planes that are not particularly regular or even in the case of material surfaces (textures) significant for the model.

For the purpose of a correct transposition into the model of material information and material culture, the import and positioning of the mesh in the BIM model must be carried out with precise 3D references.

   a. PROS
      i. Faithful restitution of particular objects presents in the relief;
      ii. Possibility to also import the surface material as a texture applied to the mesh;
   b. CONS
      i. Weighting of the BIM model, due to the density of the imported mesh;
   c. TIPS
      i. Think about possible resampling of the density of the mesh to be imported into the BIM model;
      ii. Optionally manage the more defined textured mesh as an external hyperlink to the BIM model, in an online data repository.

1. CAD 2D drawings (Image 3)

if we have a series of 2D CAD drawings, we can use them as a vector basis for modeling BIM objects.

a) We import 2D CAD drawings into BIM Authoring.
b) We use 2D CAD drawings as a vector base to model the building with BIM primitives (walls, columns, beams, floors...)

a. PROS
    i. Use vector 2D data as the basis for precise modeling of BIM objects;
b. CONS
    i. Lack of three-dimensional information;
    ii. Lack of material data (textures) or non-graphic information associated with 2D vectors.
c. TIPS
    i. Use any files as references for representations of surfaces: reliefs of masonry or flooring, cracks in case we do not have adequate photographic material surveys (raster textures);

B. 2D scans of paper documents.
in the same way as what was said in point C, we can use 2D scans of paper documents as references for BIM modeling. Obviously, we will not be able to use any snap points as in the previous case and this will make the result less precise than the other modes mentioned.

a. PROS
    i. Use scanned 2D raster data as a basis for modeling BIM objects;
b. CONS
    i. Lack of three-dimensional information;
    ii. Lack of snap points, need to model with a precision dependent on the capabilities of the operator;
    iii. Lack of material data (textures) or non-graphic information associated with 2D vectors.
c. TIPS
    i. Consider keeping raster data scanned in an external repository to avoid burdening the final BIM model.

4.3. Inserting non-graphical information into the BIM model

For the insertion of non-graphical data in the BIM model, it is important to distinguish the types before setting the links with the objects present in the model.

In fact, we can essentially distinguish into data that is useful to have present in the BIM model, and data that can be managed as external references.

4.3.1. Aggregable data in the model

These are data that can be composed of:

a) Alphanumeric string
b) Integers
c) Comma numbers
d) Date
e) External links

This data can be assigned to objects by aggregating them into specific tabs, which call us "Property

Set (Pset)". For more details on pSets, please refer to the description pages of the individual BIM objects in the example considered.

a. PROS
   i. Have a list of comparable data between the various objects;

b. CONS
   i. Care must be taken to set up a standard list of items that can be applied to different BIM objects;

c. TIPS
   i. Set up data tables in advance, so that it is easy to import them into the model through quick import functionality (e.g., using MS Excel).

4.3.2. Data not aggregable to the model

In this case we are in the presence of information that for various reasons we cannot aggregate directly in the BIM model.

Typically, these are:

- Imagery
- Point clouds
- Multimedia files (audio and/or video)
- Web pages.

For all these cases, the most convenient option is to insert hyperlinks to external repositories into the object properties. This technique brings several advantages. Among the most obvious advantages we mention the possibility of keeping in external archives data that would be particularly heavy.

a. PROS
   i. Easier to manage data that is generally particularly heavy;

b. CONS
   i. Verify and ensure that external data repositories will always be accessible over time;

c. TIPS
   i. Choose reliable repositories that guarantee the security of uploaded data as well as privacy.
   ii. Verify that links do not ask for access passwords or that they are not accessible by people outside the original internet domain.

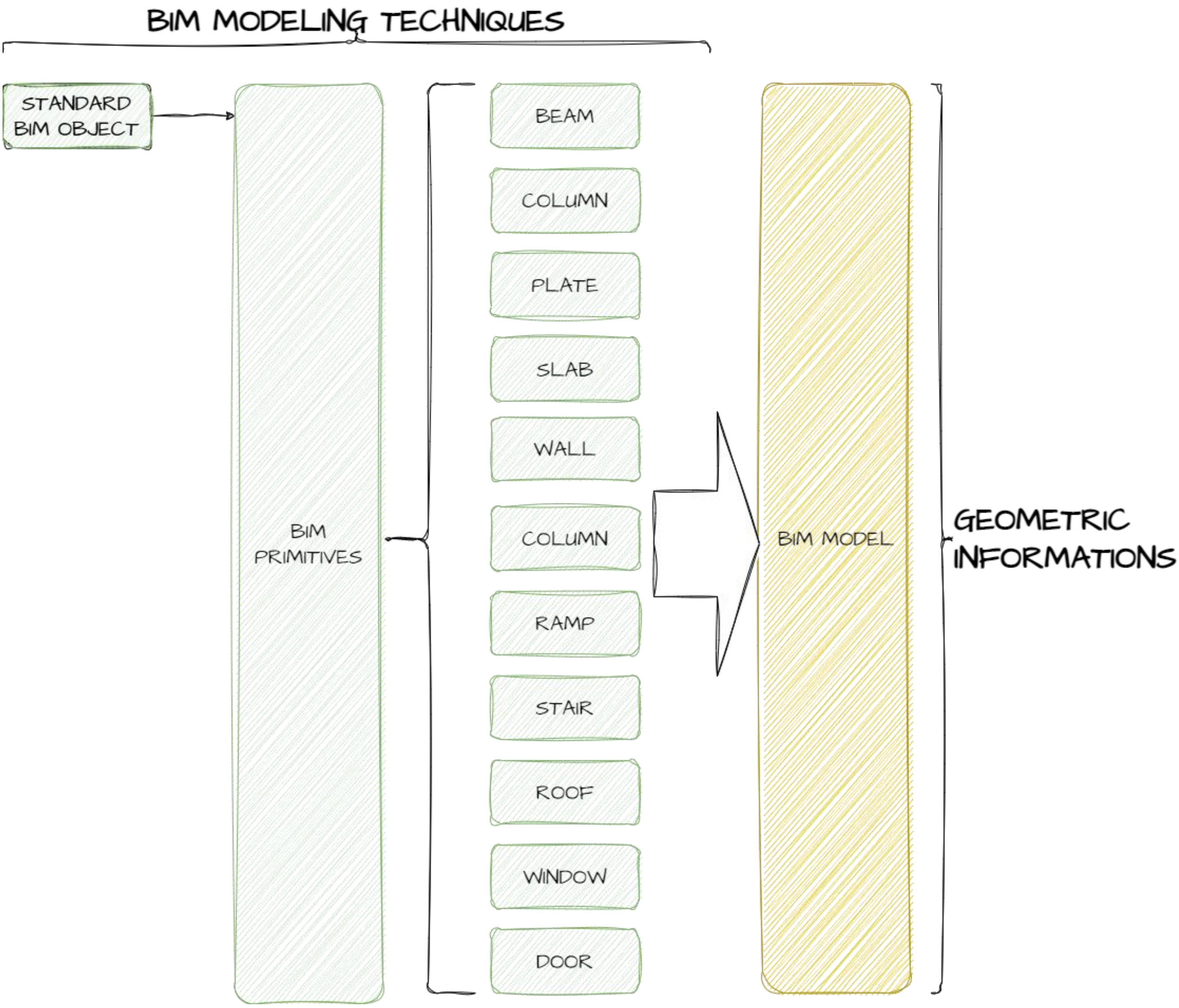

Image 3 – BIM modeling using standard 3D primitives

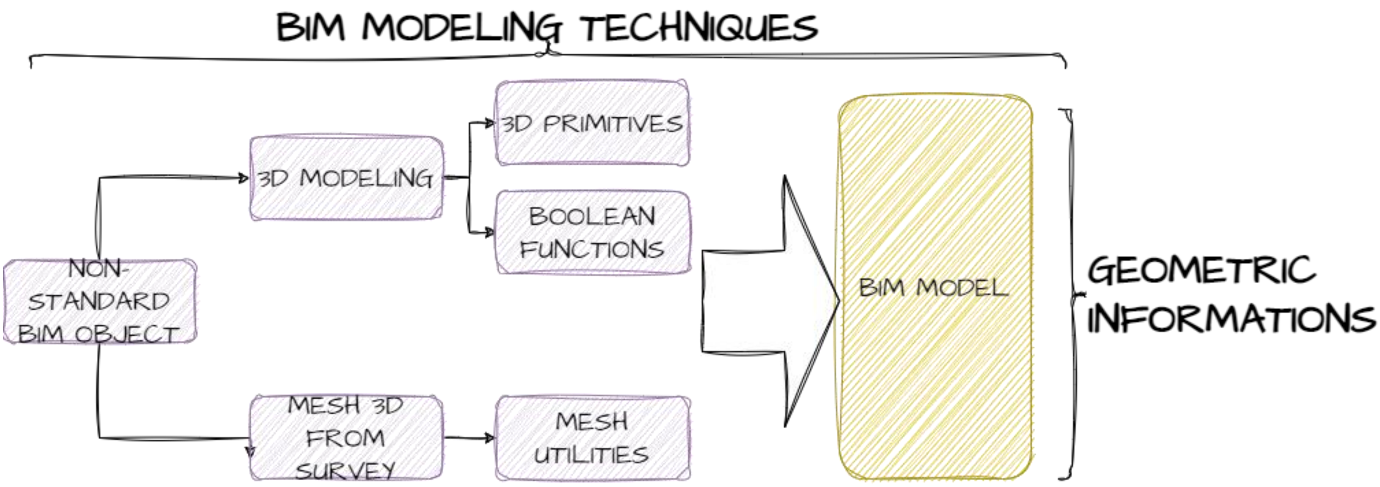

Image 4 – BIM modeling using generic3D primitives

4.4. BIM element attribute analysis

In the case of the selected example (Colonia Elioterapica of Legnano, BBPR) we considered as exemplars for the explanation of what was said in the previous paragraphs, some specific components

(Image 5 - selected elements to analize).

In some cases they were made with standard functions present in architectural BIM (wall, column and window), in other cases they are the result of what was detected with the laser instrument (bas-relief).

As you can see, a correct use of the available features allows to obtain a BIM model rich in three-dimensional information, but at the same time easy to manage at a three-dimensional level.

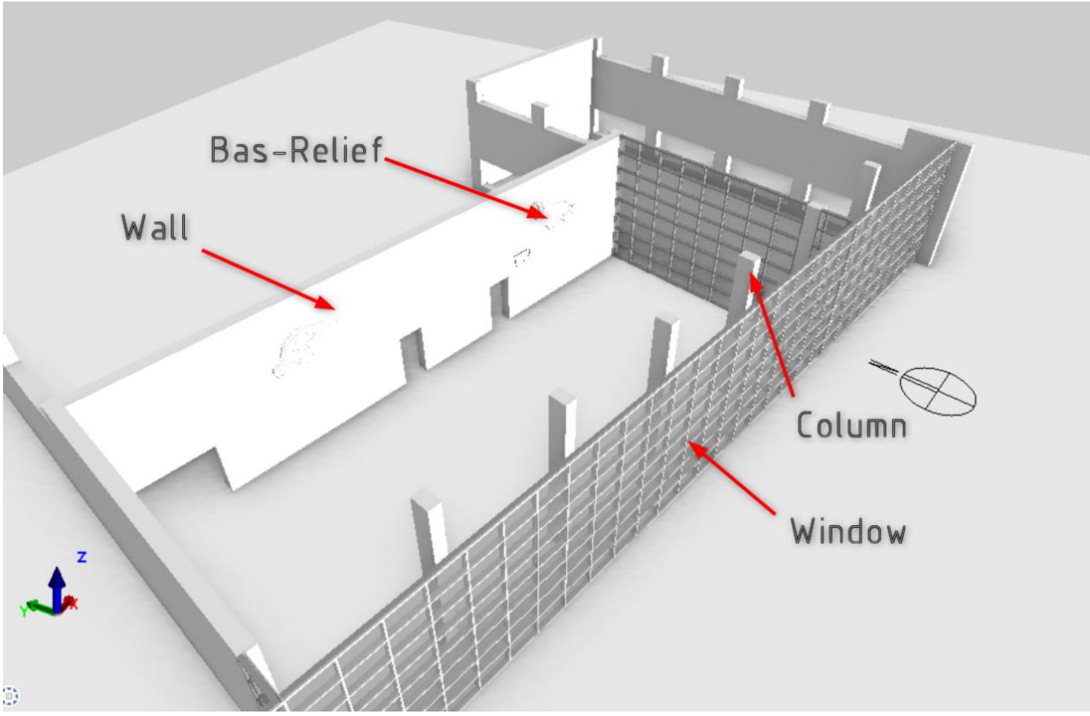

Image 5 - selected elements to analize

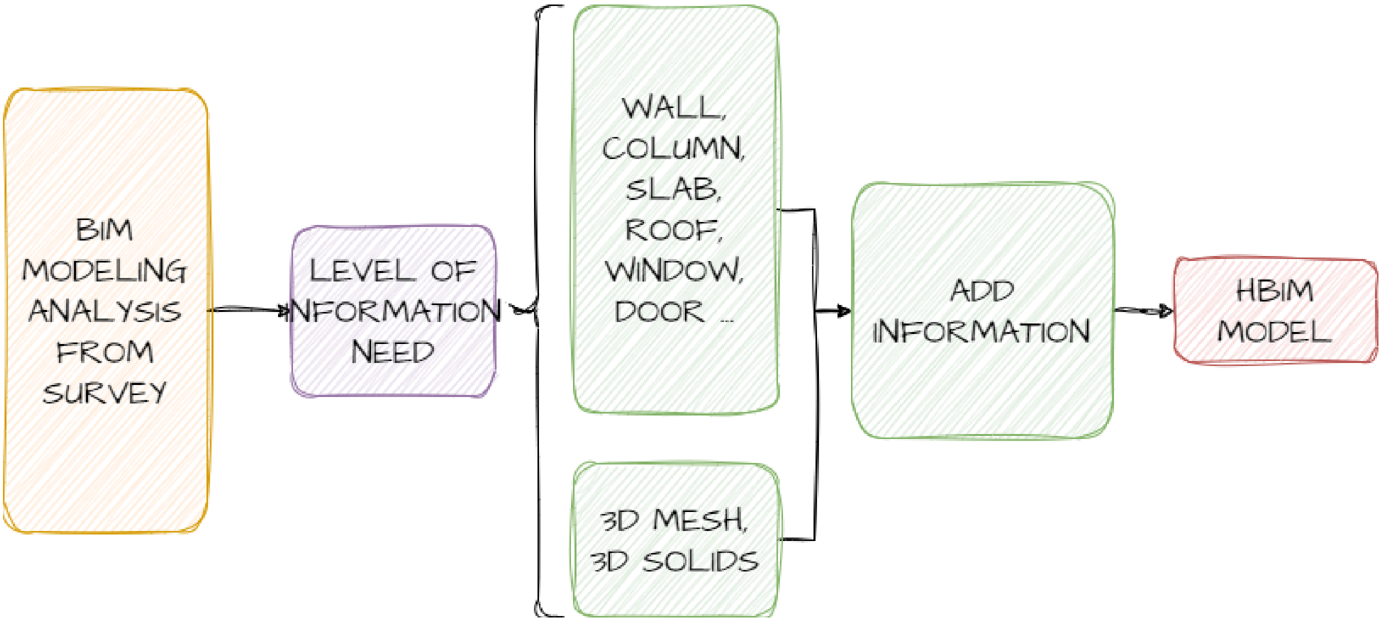

Image 6 - HBIM workflow

In Image 6 you can see the operational flow that goes from the first settings of the BIM model to the realization of the final HBIM model.

The definition of Level of Information Needs (ref. ISO 19650[12]), is particularly important to avoid focusing on modeling details that are not significant for HBIM, or not considering other objects or data that may be particularly important.

4.5. Building modeling

We do not have to explain in detail how to use the chosen BIM authoring software. For this purpose, we refer to the specific technical training on the instrument.

4.6. Overview of significant model objects

Below we see for each chosen object an overview of characteristics that are fundamental for a correct HBIM modeling.

The elements that we will see are the following:

1. Facade element
2. Floor element
3. Decoration element (Bas-Reliefs)
4. Pillar element
5. Wall element

Describes the non-graphical information in each of them. What is particularly significant is the comparison between the properties read by the architectural BIM authoring software and the properties read by the exported IFC file (in this case in IFC4 version).

To read them, one of the most popular model and code checking software (Solibri) was used[13].

This comparison allows us to understand how, beyond the possibility of transmitting the dimensional information of the project to other members of the project, it is possible to do so correctly even with data attached to the individual objects that make up the BIM model.

[12] https://www.iso.org/standard/68078.html
[13] https://www.solibri.com/solibri-office

STAGES OF DOCUMENTATION FOR THE PROTECTION AND DEVELOPMENT OF HISTORIC BUILDINGS IN BIM SOFTWARE

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