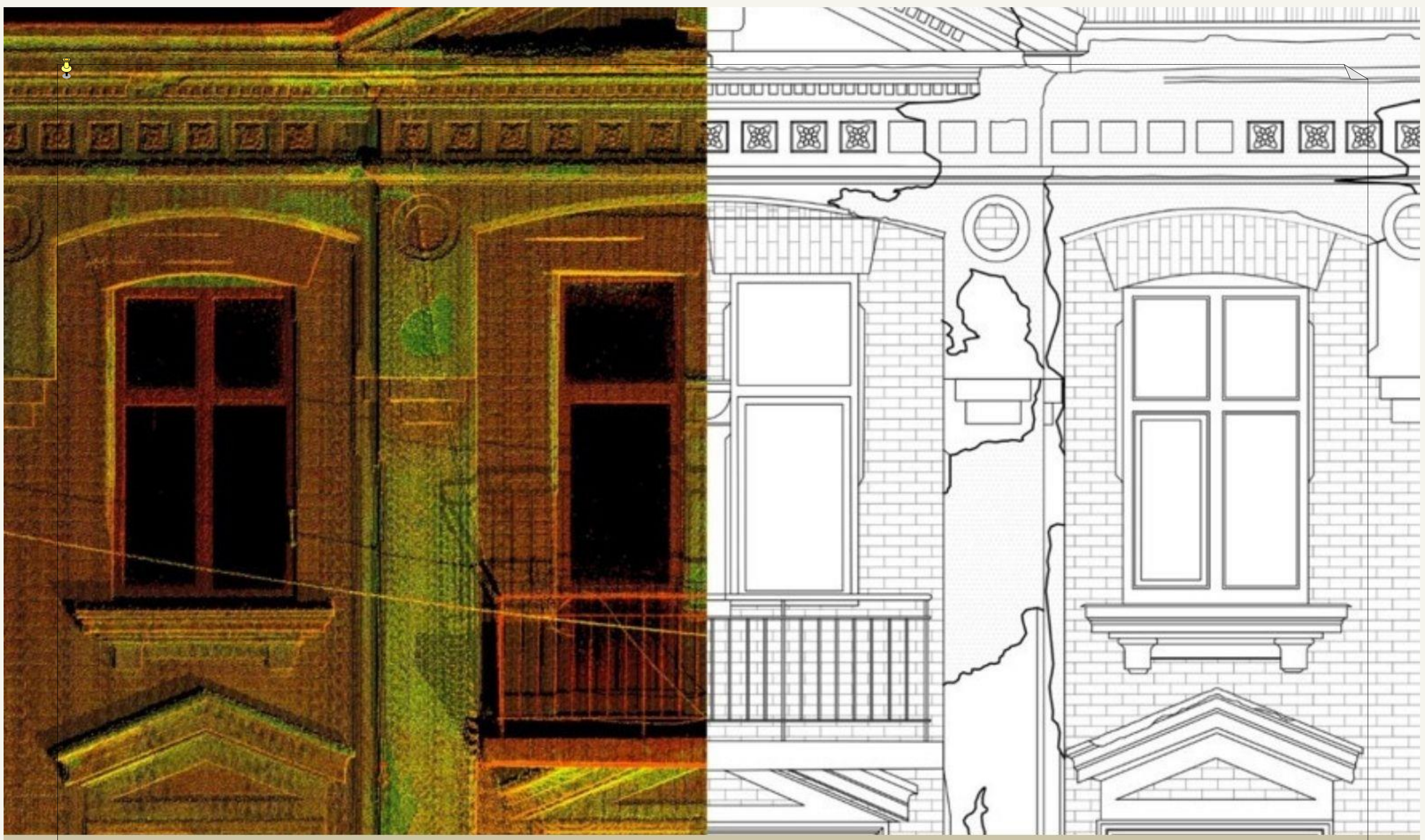

Instruction of Historic Buildings Inventory

Instruction
of Historic Buildings Inventory

MANUAL

Developed within the project

HERITAGE BIM

Publication developed within the project *Heritage BIM - enhancing digital competences of students of Architecture*

by the consortium:

- **Politechnika Lubelska, Poland**
- **Politecnico di Milano, Italy**
- **Vysoke Uceni Technicke v Brne, Czech Republic**
- **BOSCO studio, Poland**
- **Harpaceas, Italy**
- **Allplan Česko, Czech Republic**

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Key Action 2: Strategic Partnership

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1. CONDUCTING A LOCAL VISION OF THE SITE

A site inspection is also connected with a number of additional activities that need to be performed beforehand. Proper recognition of an object and obtaining information about it are often very time-consuming processes and require careful reconnaissance. Before the site inspection is carried out the preliminary works are very important that allow to identify the historic site on which the works are planned.

During the site inspection the following should be taken: a notebook, simplified plans of the building (if we have them) and a camera.

1.1. Analysis of a site archival documentation

Before starting works on an object, it is extremely important to firstly identify it. In order to properly identify an object, a number of steps have to be taken. Moreover, in case of historic buildings it is important to analyse not only the current state of the building, but also a number of changes that have taken place over the years.

To analyse the site over the years it will be necessary to study the site documentation. After determining the geolocation data of the object and the administrative boundaries of the plot, it is important to determine its successive divisions and owners. Very often it is the change of the object's owner that results in reconstruction, extension or adaptation of the object. Changes in administrative boundaries can also be important when looking for information about the extension of an object.

In addition, the current owner or manager of the facility must also be identified before works can begin. In order to carry out works on the property, it will often be necessary to obtain the owner's or manager's permission. Any works on the site should only be carried out after the owner has been informed and has given his/her consent. This applies both to research interfering with the structure of the object (excavation, digging) and completely non-invasive research (photographic documentation).

Another authority that decides on the possibility of carrying out the works is the local conservator. If the object is legally protected (entered into the Register of Historic Monuments), all kinds of works can be conducted only after obtaining permission from the appropriate conservator's office. It is important to have such a permit before starting works. In order to obtain the permit, it may be required to submit a scope of works, which must be completed in advance. The scope of works should be prepared in accordance with the guidelines that will be presented in the following chapters of this manual.

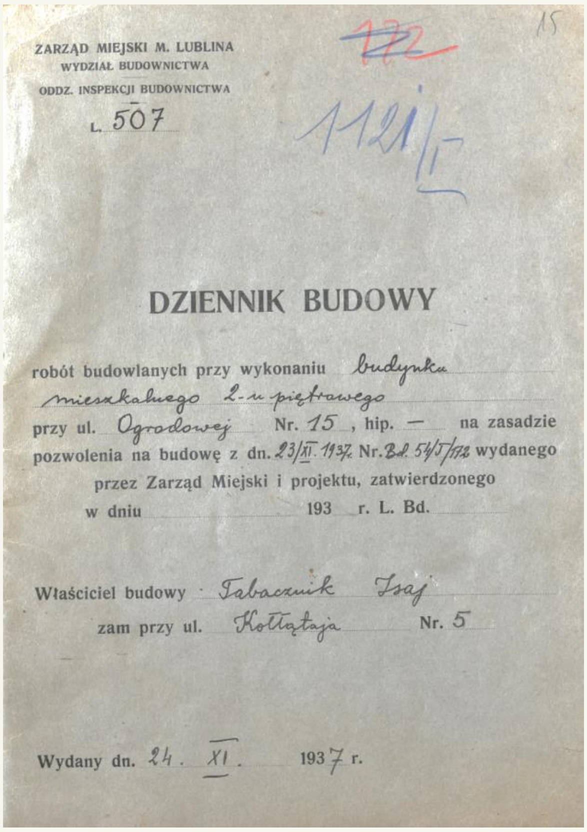
Legally protected objects should be marked in an appropriate manner. The correct marking of such an object is shown in the photograph below.

Figure 1 Designation of a historic site.

For easier identification of the object and its elements, another very important task is to perform an architectural and conservational study. Such a study is a detailed analysis of the available documentation of an object. The object documentation is usually found in the archives of the object owner and the archives of the competent authority protecting the object.

Such archival documentation may include, among others:

- sketches, drawings,
- archival architectural and construction projects,
- archival construction documentation,
- inventories, opinions, expertise,
- periodic inspections,
- cost estimates and work schedules.



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Właściciel budowy Tabacznik Isaj
zam przy ul. Kołłątaja Nr. 5

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Figure 2 The construction documentation – the construction log of the tenement house at Ogrodowa Street in Lublin, erected in 1937. – it is available in the archives of the Lublin Conservator of Monuments.

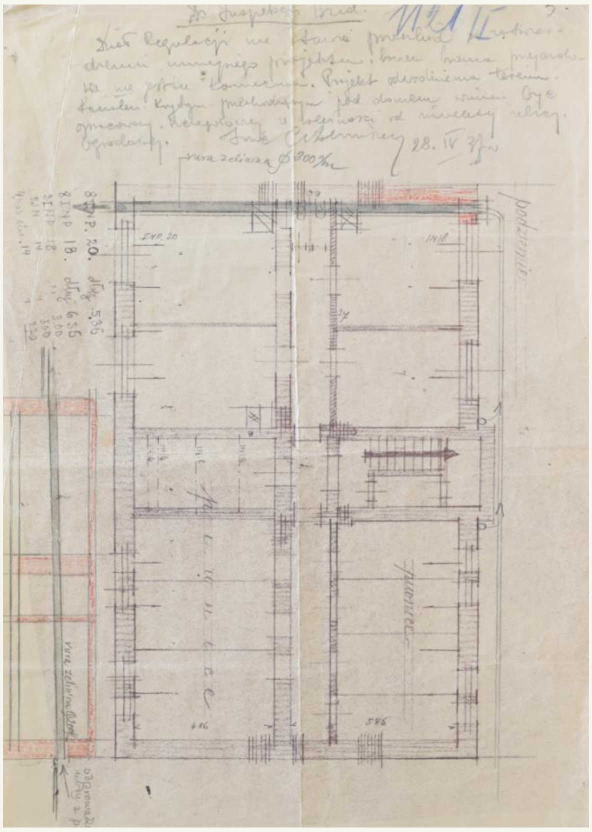

Figure 3 Drawings of the tenement house at Ogrodowa Street, included in the construction project – available in the archives of the Lublin Conservator of Monuments.

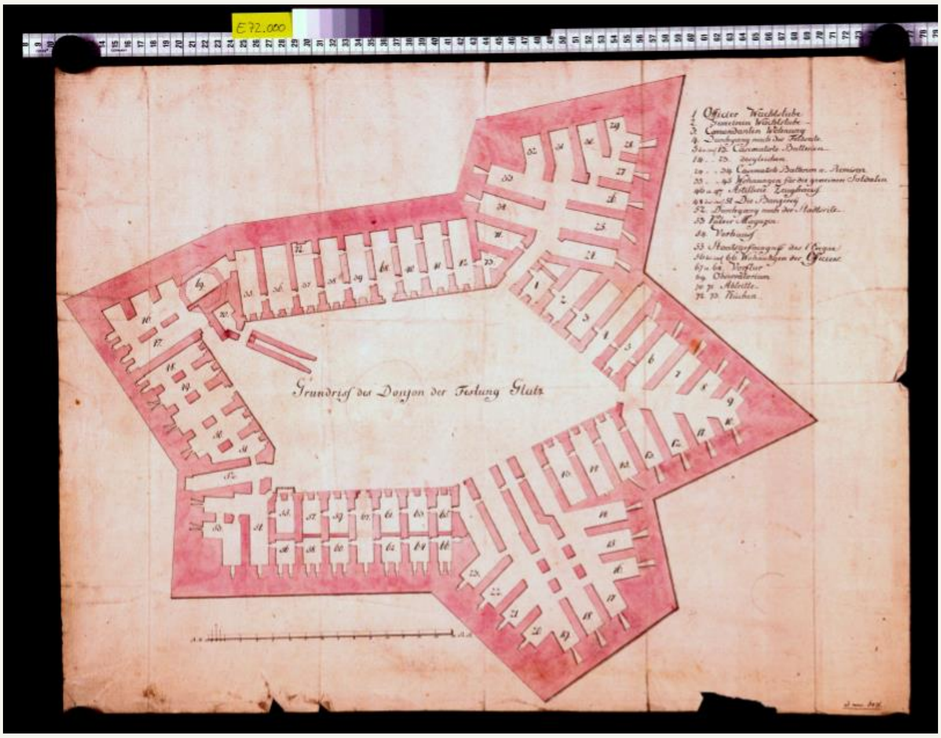

Figure 4 The donjon drawings of the modern Klodzko Fortress – available in the Berlin Archives.

The obligation to obtain appropriate approvals and permits for the construction of buildings is not something new. The first building standards appeared in the world already in the second half of the 19th century. This means that the erection of a building since that time, required the creation of appropriate documentation that today allows to identify and describe the building in detail.[1]

Obtaining and analysing archival records can be crucial in planning future works on a site. Archival documents may contain basic information about the facility. Not only about its history, but also fragmentary technical descriptions, technical evaluations and even inventories. Digital versions of the documentation are becoming more and more popular and they significantly accelerate and improve the consecutive stages of works on historical buildings.

Before starting works on a monument, it is worthwhile to look for information about it on the Internet. Currently, the majority of the resources are available publicly on the Internet.

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[1] https://www.buildinghistory.org/regulations.shtml, na dzień 04.04.2022r.

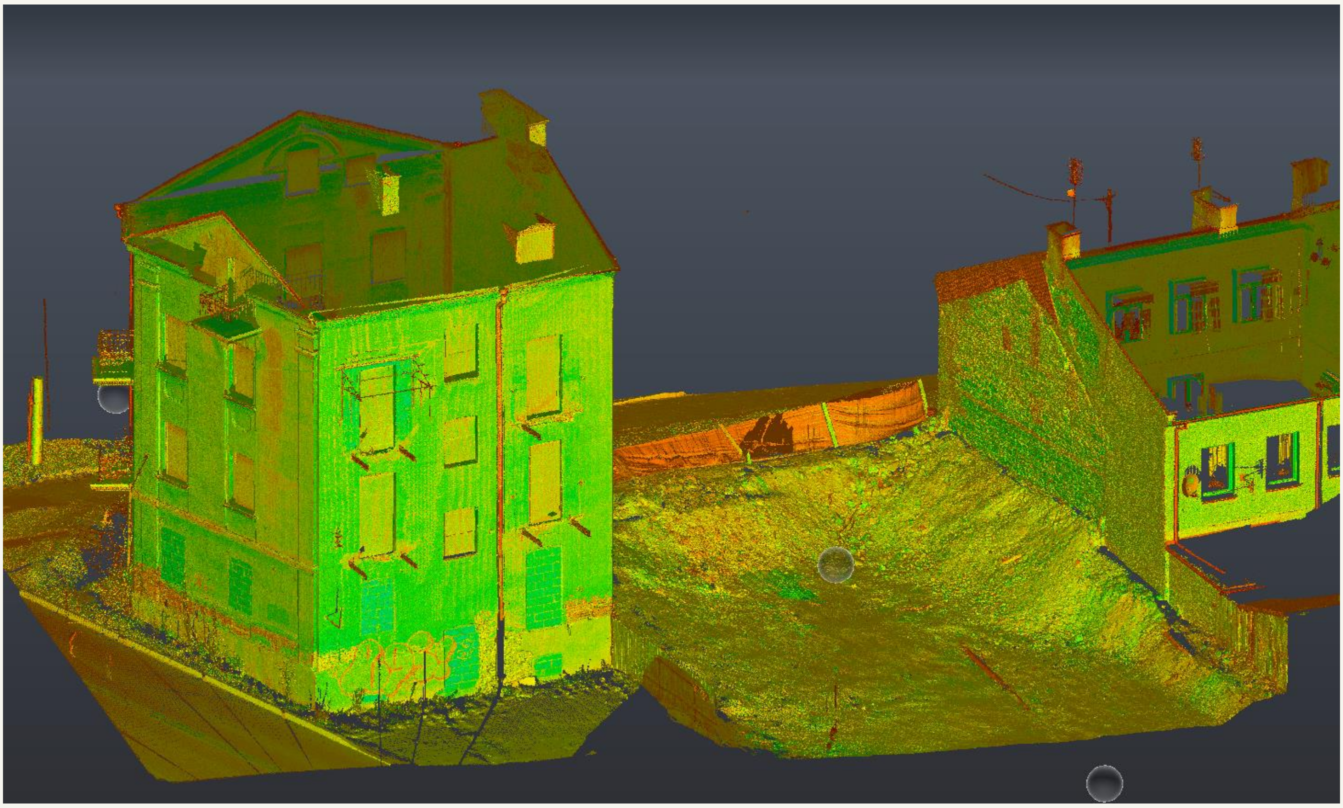


Figure 5 An exemplary digital inventory of the tenement house in Chelm, Hrubieszowska Street.

It is important to properly select and organize the documentation that will be helpful in achieving the objectives of the works conducted. It often happens that there are huge amounts of documentation in the archive. In this case, it is necessary to spend time on its proper selection, which in future works will certainly help us to carry out works and research more efficiently.

1.2. Analysis of a site archival documentation

After identification of an object and before commencement of works, a very important element is a site inspection. During the site inspection it is necessary to perform a general visual inspection of the facility and to decide whether it is possible to carry out the planned works and their scope.

It is best to start the site inspection with a visual inspection and assessment of the facility surroundings. In case of conducting surveys and measurements inside the facility, the possibilities may be greater due to the fact that it is not necessary to go beyond the parcel boundaries. An important part of identifying a site and recognizing its administrative boundaries is determining them in the field. If surveys are conducted outside of the parcel, it is possible that additional permissions will be needed from managers of other parcels and real estates.

In addition, before starting works on the object, it is necessary to make a walk along its facade walls. It is worth having a printed map showing the outline of the building and its immediate surroundings. Using a camera and noting down the observations in a notebook, a thorough visual inspection of the immediate vicinity of the building should be made. Such an inspection should include:

- access to fragments of elevations – are the elevations not covered by anything, are they not obscured by vegetation, is it possible to approach the object directly,
- closest surroundings of the site – does the profiling of the terrain allow for conducting the research, in which places it is possible to locate working stands – stands for conducting the opencast research and for locating measuring equipment (e.g., a 3D scanner or a photogrammetric camera),
- safe access to the site – are there any hazards in the immediate vicinity of the site (e.g., slopes falling down, damaged and falling off plaster).

Figure 6 Visible protection of the cornice fragments with a mesh – the Zamoyski Palace in Zamość, Poland.

Figure 7 Marking – "Attention! Falling plaster fragments". – the Zamoyski Palace in Zamość, Poland.

Figure 8 Lack of access to the facade due to overgrowing vegetation – the Szreńsk Castle, Poland.

Figure 9 Marking – "No trespassing – building in danger of collapse" – the Szreńsk Castle, Poland.

After learning about the facility surroundings and threats from the outside, the next important step is to recognise the interior.

In the case of internal parts of the building, the access to particular places and rooms should be analysed. During the tour of successive floors of the building, make sure that it will be possible to access all places necessary for documentation. Often, due to the use of the premises, it is necessary to gain access to closed rooms earlier. During the site inspection inside the building it should be assessed how much of the building is accessible and how much is restricted. This should be taken into account when planning the works. If there are commercial or residential spaces in the building, access may be limited for a period of time. This should be taken into consideration when scheduling the works to be completed efficiently.

When carrying out the inspection inside the object, potential obstacles for the application of specific measurement and research techniques should also be taken into account (e.g., a room that is too low to set up the 3D scanner workstation, a historical wall and ceiling claddings that prevent uncovering).

Another limitation will undoubtedly be the technical condition of the facility. All works should be carried out in compliance with safety and hygiene rules. It is possible that access restrictions will result from the emergency technical condition of subsequent elements of the building structure. In such a case it is necessary to prepare an individual research plan before commencing works, taking into account, e.g., reinforcing the structure or using mixed research and measurement techniques.

Figure 10 No possibility to make inventory of attic because of damaged ceiling – the historic forester's lodge in Łopiennik Dolny, Poland.

Figure 11 Lack of access to the roof truss due to its complex layout – the historic forester's lodge in Łopiennik Dolny, Poland.

After getting acquainted with the facility, it is worth conducting an environmental interview with both the owner or manager, and users of the facility. This activity seems to be crucial and should be carried out first, however, failure to visualize the object before the inspection may result in difficulties in communication when discussing technical problems.

The environmental interview is particularly important in the absence of any archival documentation. Quite often, it is during such an interview an information about previous renovation works or events that had an impact on the current condition of the facility, can be obtained. The problem is, however, the credibility of this information, most often related to its subjective presentation, lack of a technical education or only an approximate setting in time. During the interview with the user, it is sometimes possible to obtain information on existing documentation, not analysed previously.

After gathering a lot of information, the research planning of an object can be performed. Before starting the research, the assumed scope should be confronted with the technical possibilities of its implementation. In addition, the historical value of individual fragments and parts of the building as well as the complexity of their details should be taken into account. It happens that the legally protected objects have a decidedly different level of decoration. In the case of objects with a small number of decorations, high precision can be achieved using traditional measurement techniques, while in the case of a large number of architectural details, traditional methods may have certain limitations. In this case, it will be necessary to use, e.g., the photogrammetric techniques or 3D scanning.

Figure 12 Facade of a historic building with very few architectural details, the Zamoyski Palace in Zamość, Poland.

Figure 13 The Plenipotentiary House – elevation with a lot of detail in the form of woodcarving, Zwierzyniec, Poland.

Then, after confronting the scope with the technical possibilities, it is necessary to make a vision in terms of the application of measuring and testing techniques. Depending on the chosen solutions there may be further limitations. For example, too dense vegetation or unstable ground (e.g., not very rigid wooden floors) can completely exclude the 3D laser scanning method, and the location of the building may prevent the execution of the inspection using a drone without prior approvals and permits.

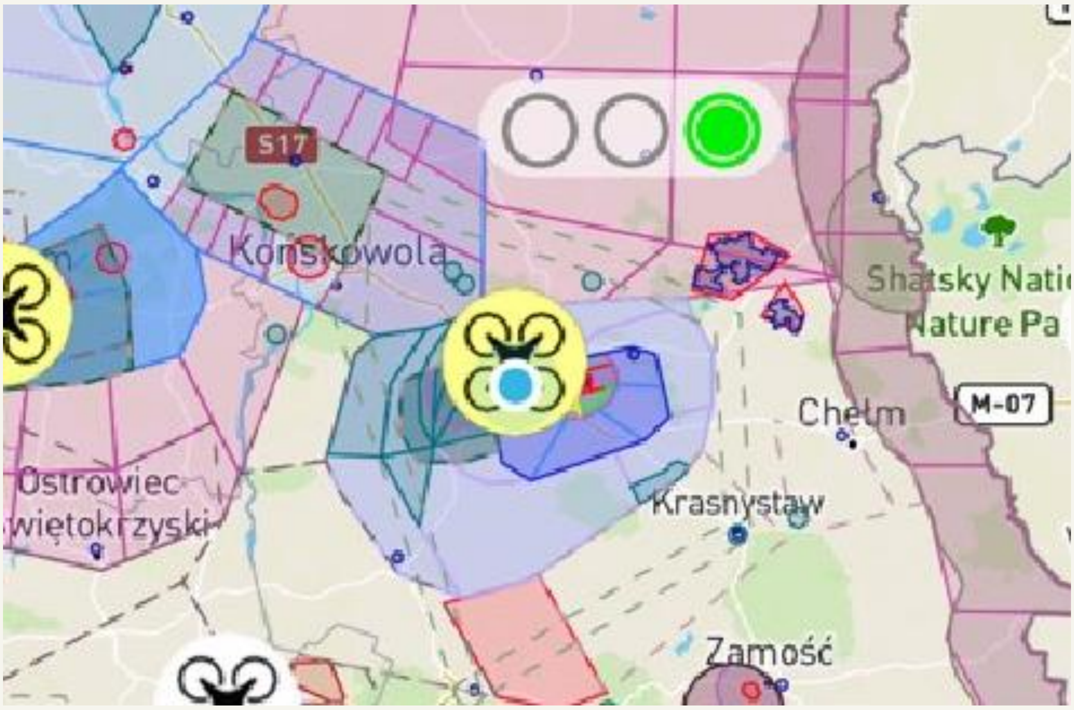


Figure 14 Examples of the drone flight zones around Lublin, Poland.

Once the initial site inspection, environmental interview, and identification of constraints and hazards have been conducted, the next step can be proceed, i.e., preparation for tests and measurements.

1.3. Preparation stage for tests and measurements

The formal consents articulated in the introduction to the chapter must be obtained before works can proceed. In the case of permit from the owner or manager of the site, it is a matter of compromise and appropriate arrangements. In the case of permits from a State authorities, including the relevant Conservation Authority, a work plan must be prepared and presented in advance.

As a part of such a work plan, the following should be done:

- Specifying the time frame of the research and works – determining when the works are to be carried out and when the building is to be taken out of use.
- Determination of measurement and research techniques and methods – determination of invasiveness of the works. Whether the works will be destructive, semi-destructive or completely non-invasive.
- Determining the location of the works – detailed marking and describing on the site plan the places where samples will be taken for testing and the uncovering of elements of the structure and finishing layers. Description of all layers that will be removed together with their historical value should be made.
- Description of the technology of possible protection of exposed elements during performing destructive tests.
- Technology of restoring the sites after the tests and exposures.

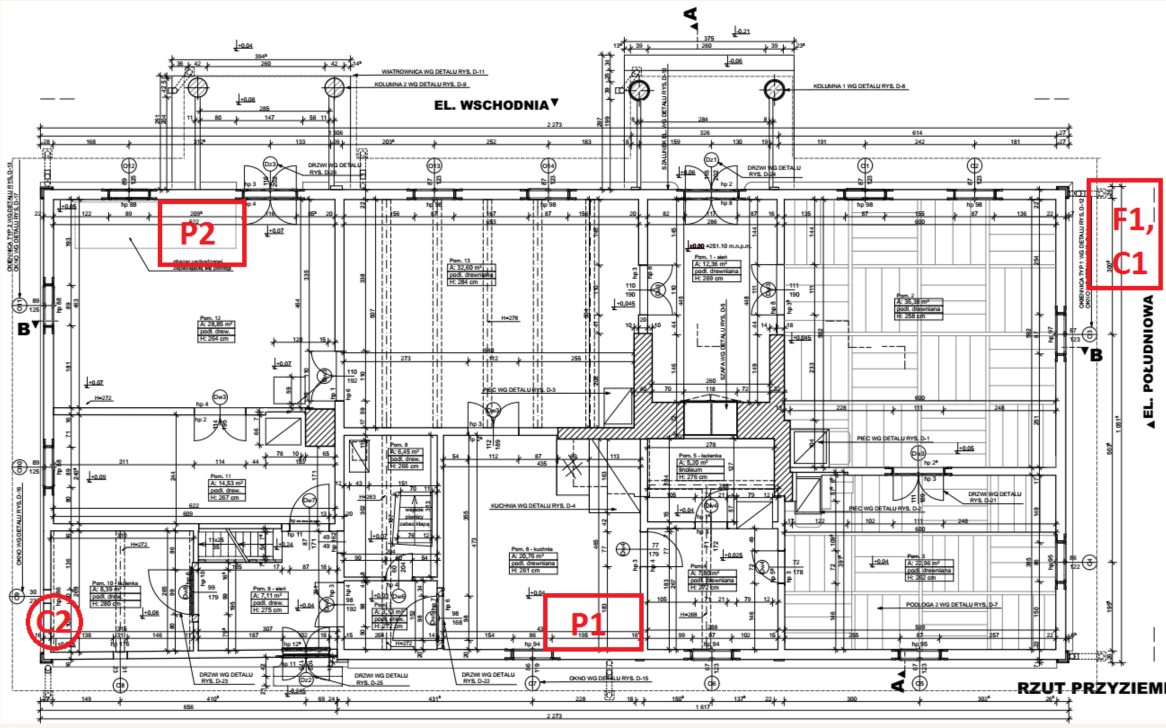


Figure 15 Exemplary designation of the research sites in the archival inventory, the historic rectory building, Frampol, Poland.

After completing all the necessary activities related to the site inspection, it can proceed to the beginning of research works, starting with detailed photographic documentation.

2. PHOTOGRAPHIC DOCUMENTATION OF THE OBJECT

Photography has been an invaluable tool in documenting cultural heritage for more than 170 years. It allows the visual appearance of buildings, objects, places, and people to be captured quickly and accurately, preserving a moment in time for the future. Moreover, unlike other visual techniques such as drawing or painting, photography is not dependent on the subjective interpretation of the artist but provides a more or less objective and complete capture of reality. However, it is limited by the 2D space of the image and the technical parameters of the equipment used.

At present, photographic documentation in the field of cultural heritage can be divided into several main categories, which will be presented in more detail below:

2.1. Archival photographic documentation

An invaluable source of information about the previous appearance of cultural heritage objects in their details. Very often it does not only capture buildings or objects, but also the contemporary context, people, events, and other information of research interest. Archival photographs can thus provide a broader cultural framework of the time they depict, which also helps to draw more accurate and richer conclusions about the researched heritage objects, in this case, historic buildings. For the classification and evaluation of historical photographic sources, the National Heritage Agency has in recent years even developed specialized methodologies for the classification and evaluation of historical photographic sources, which provide guidance on how to determine, for example, the date of the photograph and many other interesting contexts.

From the historical photographs, we are able to determine the appearance of the buildings before the more recent or contemporary reconstructions, the use of the buildings, and their equipment (e.g. furnishings and interior fittings).

They also show details of the construction and finishes, e.g. roofing, plastering, paving, tiling, etc.

It is also important to note that archival photographic documentation is not only a matter of the late 19th century or the early 20th century, but that images taken last month can also meet the criteria for archival photographic documentation if they show a situation that is no longer exists today. Indeed, very often this is the only method of documentation for many changes in buildings.

2.2. Contemporary photographic documentation

Even to this day, photography remains the most efficient method of collecting survey data.

The most basic and simplest kind of photographic documentation of a monument is simply taking a picture of the building or a part of it with an ordinary camera. The reality seen is thus immediately captured in the form of a 2D image.

Nowadays, since practically only digital photography is being used, it is possible to take hundreds to thousands of images per day, very quickly and very efficiently, without any additional costs. Similarly, the subsequent processing and archiving is mostly done exclusively digitally and the printing of the photographs is only done as part of the production of paper documentation of the building for communication with the authorities and for use in the field on the construction site. Here too, however, purely digital solutions are gradually gaining ground.

Nevertheless, it is still possible to come across classic analogue technology, which is used, for example, by some conservators. The use of classic photographic technology also has some advantages. One of these is the independence from digital storage media and the relatively high reliability of archiving, which has been practically proven over centuries. This is something that digital photographs cannot yet guarantee. It is also very often difficult to trace back to where the images were actually taken because they exist only in virtual space. Moreover, in terms of the quality of the captured images, digital cameras only reached the level of conventional photography a few years ago.

Digital photography also has one danger, which is that its speed and accessibility make it easy to lose track of what and why we are really taking pictures. With traditional photography, you have to spend much more time taking each picture and therefore more time choosing the shot and the meaning of each photograph. Especially given the limited number of frames on analogue photographic film, conventional photographs tend to be much more focused on the meaning and subject matter.

The opposite pole in approach is mobile phone photography, which has become very popular and has displaced even the stand-alone digital cameras due to its simplicity and accessibility.

However, the technical quality of the phone image is very often poor. Unfortunately, however, other types of documentation are also increasingly not even taken anymore, because "someone snapped it on a mobile phone".

The likelihood of losing such images in the construction documentation is even greater and, when necessary, it is very difficult to trace back the photographs of some situations on the devices of the persons involved.

For these reasons, we strongly recommend that all documentary photographs be taken only with a high-quality camera. They should then be processed and archived consistently so that their informational value is not lost, not only in what is captured in the photo but often also in when, where, and why the photo was taken.

One of the indisputable advantages of modern digital photography for the documentation of monuments nowadays is its use for other documentation methods, especially multi-frame photogrammetry.

Other devices that are used for the documentation of monuments can be, for example, spherical cameras capable of taking 360% panoramic images (suitable, for example, for virtual tours of places), or small drones that allow you to take pictures in places where you can't get to. Tripods or a photographic pole, either in the form of a monopod or a telescopic device for placing the camera even several meters out of the photographer's reach, are also very underrated tools.

Today there are even very specialized devices designed specifically for photographic documentation. Whether it is photogrammetric cameras or 3D laser scans capable of taking colour 360 images linked to a point cloud.

A very promising hybrid of all these devices is the Matterport technology - essentially a pair of calibrated cameras housed in a single device capable of taking 360 images automatically. Thanks to the well-known and fixed configuration of the cameras, it is possible to read the depth of space for each pair of images from this device based on the principles of photogrammetry. This whole technology was developed for the needs of the real estate market, where its main application is.

Although the Matterport device does not produce outputs that are comparable to laser scanning or cross-sectional photogrammetry, the speed and simplicity of scanning and processing the outputs make it an ideal tool for the simple passport of objects or building history surveys of buildings where there is no requirement for extreme accuracy of the acquired data.

However, for fast object mapping, this technology is more than sufficient and also allows for other practical functions, such as the possibility of additional dimensioning directly in the spherical photographs.

2.3. Methods of documentation of historical buildings and objects

Building documentation in the form of orthogonal drawings of floor plans, sections, and elevations describing the building belongs to every built structure, just as every person has a file of their medical records. As long as everything is in order and no problems are experienced, there is no reason to consult such a folder. The same goes for building documentation, except that the life of a building is usually many times longer than the life of a human being. So it often happens that during this long period of time the documentation is lost or becomes obsolete. Furthermore, the obsolescence and unusability of most documentation older than about 5 years have been accelerated by the advent of digital documentation in the 1990s and the ever-increasing demands for its accuracy and detail.

However, before we had time to get used to the digital documentation of buildings, next to which the paper drawings from the middle of the last century look more like antiques, a new era of documentation in 3D emerged, followed by the standard for building modelling BIM (Building Information Modelling or Building Information Management).

The lack of sufficiently accurate and up-to-date building documentation is therefore a sad reality of the moment, even for relatively young buildings, and for historic buildings, its absence is more the rule than the exception. If there is a need to rebuild, reconstruct, legalize an unregistered building, or even demolish a building, it is always necessary to have up-to-date plans of the building, whether for the competent authorities or for the designers or architects. However, documentation for research or archiving purposes is becoming increasingly important, especially for listed buildings. A separate chapter is the documentation of buildings threatened with demise, either because of their structural and technical condition or because of imminent natural disasters or war conflicts.

The process of producing construction documentation for a building can also be seen as reverse engineering where we proceed in the opposite direction to the construction of a new building. At the beginning of the construction of a new house, the investor's intention is translated by the designer into project documents, according to which the construction company subsequently carries out the construction. In the case of a building already standing, it is first necessary to take measurements in real life in a suitable way and to draw passport documentation of the building based on these measurements, which would sufficiently describe the appearance, dimensions, and structure of the building to be surveyed. There are several specific measuring methods available and the most suitable procedure is always chosen according to the extent, nature, and condition of the building and the client's requirements. A different method may be used for a garage survey, where a tape measure or a pocket Laser measure and a simple sketch will probably suffice. However, when surveying a multi-story apartment building or a castle, such simple tools will no longer suffice and we will have to use more complex and costly methods.

When choosing a method, we can currently choose from the following methods and their combinations, which we will now simply describe and compare their strengths and weaknesses:

2.3.1. Surveying using a tape/laser measure (orthogonal method)

A fast, simple, and inexpensive method, suitable for simple single-story, small-scale orthogonal objects with flat roofs. The data measured in the field are recorded into a sketch and then rendered in a CAD environment in the office as construction plans and supplemented with necessary details such as dimensions and descriptions.

2.3.2. Surveying using a Total Station (polar method)

A geodetic method using a specialised instrument called a Total Station, i.e. a device for the accurate measurement of angles and lengths. Measured data are stored in memory inside the instrument using coding or in combination with a measurement sketch. The measured data (polar coordinates) are downloaded to a PC in the office, where the Cartesian coordinates are calculated from them for the individual points measured in the field, these are then loaded into the CAD environment and by joining them together a final plan of the building is created, which is then also supplemented with dimensions and other details of the building description. This method is suitable for most construction objects, regardless of their scale or shape complexity. The disadvantage of the polar method, however, is that for larger buildings the data collection is slow, and only selected discrete points are targeted from the complex reality of the building, such as room corners, window corners, ceiling heights, etc. If any of the important points are missed during the measurements, it is necessary to go back into the field and re-measure the missing data.

2.3.3. Surveying using a 3D scanner

A very fast and effective method for the vast majority of buildings and structures, with the exception of glass and glossy surfaces or water surfaces. A laser scanner is, in simplified terms, an automatic measuring machine working on the principle of a laser distance meter that shoots laser pulses very quickly into its surroundings and uses them to create a so-called point cloud, representing an accurate digital impression of the surface of all objects visible in the scanner's field of view. The field of view of the instrument is usually 360° horizontally and 310° vertically. The so-called dead angle is just the cone below the instrument where the legs of the tripod on which the laser scanner is mounted are located. During the measurement, the instrument is gradually positioned at suitable locations on the exterior and interior of the building so that the laser pulses are fired to cover as many of the buildings' surfaces as possible to obtain a digital imprint. Subsequently, the individual point clouds corresponding to each scanner position during the measurement are combined in the office to form an overall point cloud describing the measured object. This point cloud is then loaded into a suitable 3D software environment and, in simplified words, "traced" according to the measured data into standard passport documentation of the object, such as floor plans, vertical sections, and elevations.

This method has the great advantage of capturing continuous data (as opposed to the previous method of measuring only pre-selected important points), so any errors in the evaluation can be detected without the need to return to the surveyed site. From the measured data, it is also possible to retrospectively evaluate additional sections or elevations of the building as required, since the scanner captures a complete spatial imprint of the building on a given date during the measuring process. In addition, modern scanners are equipped with RGB cameras and can take panoramic photos of each scanned cloud, with which the point cloud can be coloured in realistic colours. These data then make it easier to orientate the object and speed up the processing of the documentation.

2.3.4. Surveying using photogrammetry

The use of this method was made possible by the rapid development of software for correlating images from conventional cameras over the last decade. In this method, it is necessary to take a sufficient number of images of an object with a suitable overlay, then upload the images to a specialized photogrammetric program and let the program reconstruct the elements of the external and internal orientation of the camera. Or to calculate from which photo was taken and to place these photos in 3D space, where the positions in space are then calculated using the method of intersections of "rays" sent from identical points captured in multiple photos. This also produces a point cloud of hundreds of thousands to hundreds of millions of identified points, similar to a laser scanner, but with the difference that the individual points are not the result of the laser beam reflecting off the surface of the object being measured, but only the intersection of at least two optical beams passing through several images where the same point is overlapped.

The advantage of this method is mainly the speed of data acquisition in the field and the complexity of the measurements, where the spatial representation of anything captured in the source photographs can be calculated. The existence of the images also allows verification of the evaluation and capturing of the true colour of the resulting model. However, the disadvantage of this procedure is the poorer accuracy of the method, since it does not directly measure distances and real dimensions of the object, but only counts the relative positions of points and images in space. The results are also dependent on suitable light during the shooting and the need to signal and then geodetically locate a sufficient number of tie points, which enable the dimensionless 3D model to be correctly oriented and enlarged to the real scale if higher measurement accuracy is needed. However, the photogrammetric method is ideal for making accurate models of sculptures or complex details of facades, etc. It also allows measurements using photographs taken by unmanned aerial vehicles (drones), thus enabling the surveying of places or areas inaccessible to humans, such as rooftops, towers, castle ruins, or the landforms of large areas.

2.3.5. Documentation of historical buildings

When deciding which of the above methods to use, it is advisable to visit the object of interest and become familiar with its state and the surrounding conditions, such as accessibility for measuring equipment, the condition of the vegetation, the level of detail, and the complexity of the shapes to be measured. In most cases, it is appropriate to combine several methods, depending on which method is most effective for the survey of the particular type of object or part of the object. A typical example is to measure the roof shell and façades of a building by photogrammetry using a drone and a laser scanner, while interiors are measured exclusively with a laser scanner, as the latter is the only one that can also measure the white areas of walls without the visual detail required by photogrammetry and can also reliably link scans of individual rooms and floors to each other.

These advanced methods of measurement and documentation are then particularly important when working with cultural heritage, where very often it is not enough to simply capture selected points to draw a simple schematic plan of a building, but where the essence of documentation is instead to accurately capture the spatial relationships within the building and the complex shapes of often artistically rendered elements and details. Whether it be sculptures, architectural elements, and ornaments, or the accurate depiction of the shape and texture of the masonry of a castle ruin with the marks and imprints of structures that have already disappeared. Not to be overlooked is the documentation of the visual aspect of the buildings by means of coloured photo-plans, unfolded elevations of curved surfaces (e.g. frescoed decoration on vaulting), or the capture of complex visual information, such as the surface damage of facades or wall paintings.

Accurate documentation of monuments also enables their improved research, better project preparation, and subsequently archiving of data about the appearance of the object at a given time. A significant aspect is also the possibility of precise calculations of volumes, surfaces, and weights of various parts of the building based on their exact 3D measurements, which is particularly important for the budget part of the project design and structural calculations. Thanks to the precise spatial survey, it is also possible to identify the different construction phases of a building, identify structural failures of buildings and their causes (deformation of structures, spatial relationships between structures on different floors of the building, etc.), and then to respond to these findings in the planning of changes or protective measures, which can thus be more economical and accurate. It is also possible to continue surveying the building during the construction works, thus refining the measurements of its components and documenting the changes that occur. The very high precision of the survey also allows monitoring of whether the building continues to deteriorate, whether there is any movement of structures, etc.

The detailed documentation of cultural heritage also plays an important part in its subsequent presentation, whether in the form of further expert research of the object, the creation of its digital and physical models, or the presentation of the evolution and lost phases of the building's history.

In current practice, new technologies for documentation and design in the construction industry are also rapidly growing in importance, especially in relation to the previously mentioned BIM technology. With a completely digitized process of designing, planning, and realizing buildings, it may soon no longer be necessary to create traditional 2D drawings and manually 'render' a 3D record of reality, but it will be possible to work directly in a 3D environment with point clouds representing the real building, without the need for its 2D interpretation.

3. TRADITIONAL PHOTOGRAMMETRY

Digitization and the huge increase in the computing power of modern computers have brought radical changes in many technical fields. One of the basic surveying methods - photogrammetry - is among those significantly affected. It is a non-contact method in which measurements are not made directly on the object of interest, but indirectly on photographic images, referred to as a survey images.

The invention of photography in the 1820s and its subsequent development led quite naturally to attempts to use the captured image to document important monuments. Albrecht Meydenbauer, who is also considered to be the founder of the photogrammetric method, was the first to come up with this idea in 1860. He constructed the first photogrammetric camera and in 1885 was the founder of the Royal Prussian Photogrammetric Institute (Königlich Preussische Messbild-Anstal). This created the first photogrammetric institution in the world, which was able to document approximately 2,600 cultural monuments between 1885 and 1920. The archive of the photogrammetric images (about 20,000 photographic images on glass plates measuring up to 40 x 40 cm) still exists today and is administered by the Brandenburg State Office for the Preservation of Monuments. Many of these images were used in the reconstruction of important building monuments destroyed during the Second World War.

The survey image is a photographic picture is the central projection of the image rays that come from the photographed object (subject), pass through the lens of the photographic device (camera), and fall on the light-sensitive layer of the recording medium, which may be film material or a digital image chip.

If a photographic image is to be used for measurement purposes, it is necessary to know the geometrical parameters of this projection, which we refer to as the elements of internal orientation. In older photogrammetric cameras, which recorded images on film material or glass photographic plates, we encounter the term frame marks. These are mechanically or optically highlighted points that were transferred from the camera frame to the measurement image at the time of exposure. The coordinates of these frame marks had a clearly defined relationship to the centre of the projection and thus allowed the geometric parameters of the projection to be recovered after photochemical processing (development) of the acquired images. Modern digital cameras do not use frame marks because the relationship of the centre of projection to the position of the image chip is determined by the fixed design of the device.

The elements of the internal orientation are usually given in mm (sometimes pixels for digital images) and are determined with high precision (0,01 mm). This precision is absolutely necessary, as failure to do so directly affects the accuracy of the final measurement. The analogue measurement image could not be altered in any pictorial or geometrical way after it was taken, so most older photogrammetric cameras were of a fixed design, where it was possible to ensure maximum stability and accuracy of the inside orientation elements, which were determined in specialized optical laboratories.

However, the preference for accuracy was very often at the expense of mobility (higher weight) and variability, as the fixed focal length design did not allow images to be taken from different distances while maintaining the same level of detail. In contrast, modern solutions based on the concept of digital interchangeable lens cameras, often of the zoom type, offer the opposite, although not entirely at the expense of accuracy. In fact, there are a number of software solutions that can restore the elements of the internal orientation (so-called calibration) by means of calibration arrays or within the block alignment of the acquired measurement images (so-called autocalibration) and thus significantly improve their deployment, especially for the increasingly popular cross-sectional photogrammetry working on the principle of optical correlation. If the image is to be usable for the acquisition of measurement data, it is essential to link it to the chosen coordinate system. This process is referred to as image orientation and is actually the recovery of the exact position of the centre of projection and the direction of the shot axis at the time of exposure (acquisition). The result of this process are the so-called external orientation elements. From a mathematical point of view, finding the elements of exterior orientation is one of the most complex photogrammetric processes, since each measurement image represents 6 unknowns in the input. However, this means that only in the case of stereophotogrammetry, which works with two images, it was necessary to solve equations with 12 unknowns. Here, too, we can find the main reason why the increasing power of computers has made such a significant impact in this field. It has made it possible to process multiple images simultaneously, i.e. multiple equations with multiple unknowns.

3.1. Principles of modern multi-frame photogrammetry

In the scientific literature dealing with photogrammetry, there are attempts to divide it according to various criteria. If we look at the division according to the number of images processed simultaneously, we encounter the designation single-frame and multi-frame photogrammetry. The former is one of the oldest methods of documentation and in the current 3D digital space it finds its important place in the 2D presentation of spatial data in the form of orthorectified images. The designation "multi-frame" covers the two most important and currently most used methods of processing measurement images - stereo and intersection photogrammetry.

The stereo-photogrammetric method of evaluating surveying images was introduced in the early 20th century and its principle has remained virtually unchanged until today. It is based on the basic physiological property of healthy human eyes, which is natural spatial perception (natural stereoscopic perception). The perception is created in the brain by combining two different images captured by the left and right eye when observing reality. This fact led to the idea of replacing reality with photographic images that would simulate the activity of the eyes during observation (stereoscopic pair). The result is the so-called artificial stereoscopic perception, which is a kind of virtual spatial model of the object (stereo model) captured in the stereoscopic pair.

The earliest variant of stereoscopic model creation (which lasted throughout the use of analogue images) was an optical solution that used a stereoscope (a set of two eyepieces and several optical prisms or mirrors) to allow separate viewing of two stereoscopic images at a suitable magnification. Current digital stations use modern tools for displaying 3D information in the form of 3D monitors (anaglyph, polarizing, or page flipping glasses) or special arrays of two monitors with semi-transparent mirrors. The basic condition for taking stereoscopic pairs of measurement images is to maintain the parallelism of the axes of the images and also sufficient overlap between the images because the stereoscopic perception is created only in the overlapping space of the images.

For spatially complex or larger objects, more stereoscopic pairs are necessary. In aerial stereophotogrammetry, the images are taken in rows with a minimum image overlap of 60 % so that two consecutive images form an appropriate stereo pair. For larger units, rows are stacked in blocks so that the minimum overlap between rows is 30%. Stereophotogrammetry is currently most widely used in aerial photogrammetry for mapping and the creation of 3D digital terrain models. It is an efficient method that achieves excellent results in terms of accuracy thanks to modern high-resolution digital imagery.

It is the only photogrammetric method that allows the evaluation of non-signalized points based on stereoscopic perception. For this reason, it has also become an indispensable measurement method in the documentation of cultural monuments. Its only disadvantage is that it only provides vector data.

3.2. Intersection photogrammetry

Intersection photogrammetry is the oldest photogrammetric method, which came together with the first survey images as a way to solve the documentation of monuments by photography. Its principle is based on the simple geodetic problem of determining the position of points - intersecting forward from angles. Thanks to the knowledge of the elements of the internal orientation of the photographic camera, it was possible to replace the measurement of angles with a theodolite in the same task by measuring the image coordinates of the corresponding points directly on the acquired survey image.

In spite of its undeniable advantages (high accuracy, simpler image acquisition), this method was replaced by the stereophotogrammetric method relatively soon after its inception, mainly because of the higher laboriousness in the evaluation of intersection photogrammetry. The necessity of unambiguous identification of each point on several images did not allow efficient collection of a large number of points, and so the main domain of this method became engineering and monitoring of deformations of structures. The advent of digital technology, particularly in the field of photographic image acquisition and post-processing, has enabled the return of this method, which is now enjoying a renaissance. Digital images enter the process not only as photographs but also as data files which, thanks to the enormous increase in computing power of modern computers, can be processed largely automatically (block orientation, optical correlation of images) and also in significantly larger quantities of hundreds to thousands of photographs.

Modern intersection photogrammetry does not require any expensive technical equipment (it is basically a powerful PC + specialized photogrammetric software) or special expertise. Thanks to this fact, it finds application in many fields, especially in the creation of 3D models, their visualization, and presentation. However, the relative simplicity of taking images with digital cameras and the user-friendly environment of many processing software may give the impression that anyone can be an "expert" in the digital environment. This makes it all the more important to constantly remind ourselves that any technology is only as good as the people using it.

3.3. Examples of the use of modern intersection photogrammetry

3.3.1. Documentation of building heritage

Recently, with the development and availability of drones, photogrammetry is becoming a standard tool for the documentation of building heritage, usually in combination with other surveying methods, especially 3D laser scanning. It is conveniently used for documenting parts of a building that are inaccessible to humans and therefore invisible to the scanner, such as cornices, roofs, towers, or facades. By combining laser scanning and photogrammetry data, the greatest geometric detail of the 3D model can be achieved, as well as the best visual quality of the textures. From the 3D model thus captured, it is then possible to generate accurate raster photo-plans realistically depicting the actual appearance of the buildings, as well as any number of ground and vertical sections or other orthogonal projections of the building. It should be noted, however, that the processing of 2D vector drawings is still a largely manual activity, as no automatic tools can yet correctly interpret the recorded reality of a building into the construction drawings.

Historic buildings are by their nature ideal subjects for this technology, as they are characterized by complex irregular geometry, difficult to measure details, and, unlike new buildings, a visual variety of surfaces. From a standpoint of automatic 3D model evaluation technology from photographs, weathered and damaged plaster, stone walls, damaged irregular pavements, and other visually complex surfaces where the software can safely identify a multitude of unique points are ideal. On the other hand, the weakness of photogrammetry in building surveying is plain white walls and ceilings, where the software has nothing to grab onto when identifying identical points. Monotonous monochromatic surfaces with no visual detail thus create errors and holes in the resulting model. The same is true for glass surfaces, mirrors, and high-gloss materials such as polished metals. In this case, it is necessary to use different technology, such as a 3D scanner for whitewashed rooms, or overlaying glossy or transparent surfaces during shooting. Another solution is to spray e.g. shiny metal objects with special easy-to-remove paints, like chalk spray, which creates a temporary matte film on the surface of the metal objects, allowing them to be photographed and the model to be calculated.

Another pitfall of photogrammetric documentation of buildings is the possible inaccuracies caused by the correlation of images in poorly accessible locations - for example, between two rooms connected by a door. And then the dimensionless-ness of the resulting 3D model. For this reason, it is necessary to think about the location of the tie points, which could be uniquely identified on the 3D scan, and whose spatial coordinates must be determined in the field by other geodetic methods. With the help of the tie points, it is then possible to orient the photogrammetric model correctly both in the horizontal and vertical direction and, to geographical coordinates, for example. And also to determine the correct scale of the model so that it corresponds to reality and dimensions can be measured from it.

3.3.2. Documentation of wall paintings

The photogrammetric method of documentation is particularly suitable for the documentation and presentation of murals. The graphically inhomogeneous surface of the walls, vaults, and other surfaces of the building allows for a reliable grouping of individual images. The resulting textured 3D model can then be used not only to process the orthogonal projections of the building but especially to obtain unfolded views of the curved surfaces of the buildings. In this case, the required resolution of the resulting images of the paintings (pixel/mm) is the determining factor for the processing, from which the resolution requirement and thus the number of source photographs is then derived.

3.3.3. Documentation of artistic heritage

Of course, any objects other than buildings can be documented using photogrammetry. Preferably, it can be used for documentation of sculptures, furniture, or other artefacts, but also graphic works and paintings, where thanks to the principle of precise compositing of multiple images using specialized 3D software it is possible to eliminate glare on the painting, to photograph in detail even large-scale paintings, or to obtain an undeformed unfolded view of graphic works that are on uneven surfaces in the original.

3.3.4. Documentation of archaeological excavations and findings

A specific and widely used category is the use of multi-frame intersection photogrammetry in archaeology. Due to the complex shapes and usually varied "textures" of the surfaces imaged, photogrammetry can be used for rapid and accurate documentation of both the excavation situation in the field and for digital targeting and archiving of individual objects found. Photogrammetric documentation is an ideal tool here because of its speed, accuracy, and affordability. Above all, it is invaluable for its ability to record the real situation with all its details without the need for immediate interpretation. Everything is captured and documented in the form of a series of photographs and a "coloured" textured 3D model in real scale.

3.4. Case study - Documentation of castle ruins

The geodetic documentation of castle ruins is one of the most difficult tasks. This is due to the fact that most of them are situated on the top of hills or at the ends of cliffs. Very often, we find next to each other the remains of architecture or other relics of walls, rock outcrops, and the remains of earth fortifications in the form of ditches and ramparts. The situation is further complicated by vegetation. Few castle ruins are lucky enough not to be overgrown. Usually, however, it is because another factor prevails - the rock. The classical geodetic polar method encounters the difficulty of access to some parts, which borders on dangerous in the case of rocks, and the situation is not made any easier by the often very vague morphology. The fact that regional archaeological or conservation organizations do not have suitable measuring equipment or capacity also plays a role. Approaching a commercial surveying company is usually beyond the financial means of the client, given the difficulty and time required for the measurements. The situation is not made any easier by the DMR 5G laser scanning data (Digital Relief Model 5th generation - available on the CTZK portal), because in most castle ruins, where vegetation, rock outcrops, and masonry remains to interact closely, point cloud filtering fails. In the search for a suitable procedure, the use of aerial photogrammetry has proved to be an interesting and relatively economical option for the position and elevation survey of these objects. The actual surveying procedure consists of several steps:

- **field reconnaissance** - this is basically a field survey, the aim of which is to get acquainted with the site and to find problematic places that cannot be located from aerial photographs - shaded areas, rock overhangs, the ground remains of masonry (1-2 rows of stones), etc.
- **project of the survey flight** - considering the relatively small scale of the site (only hundreds of meters), two cross axes were proved suitable. The intersection of the raid axes is chosen according to the specific configuration of each site (e.g. centre of gravity, the centre of the palace building, the highest point of the site, etc.).
    - The minimum number of images per infestation axis is 3.
    - Resolution of the measurement image - approximately 2-3 cm/pixel.
    - Overlap of stereoscopic images - 70-80% (depends on site morphology).
    - The direction of the first axis - in the general direction (depending on the terrain

configuration and shape of the site)

- **Aerial photography** - is carried out strictly in a period without vegetation. The ideal time is pre-spring or early spring. The sun is sufficiently high above the horizon and the lower level of vegetation is flattened after winter. A professional aerial photography company provides the imagery. In order to reduce the costs associated with flying to a site, it is advantageous to plan to shoot multiple sites at once in a campaign.

- **photogrammetric orientation** - the survey images are combined by photogrammetric procedures into one block, which allows the necessary stereoscopic pairs to be assembled. For the connection to the Czech national coordinate system (S-JTSK), it is possible to use geodetically oriented so-called tie points (uniquely identifiable on the images) or parameters of the elements of the external orientation from direct georeferencing of aerial images (AERO CONTROL - GNSS + IMU system). The real accuracy of the connection to the S-JTSK system is around 5 cm.

- **photogrammetric positioning and DMT (Digital model of Terrain)** - in stereoscopic mode (stereophotogrammetry), significant positioning elements (roads, objects, etc.) and edges affecting the terrain course and plan points in an irregular network are vectorised to optimally represent the terrain course. For the preserved relics of the torsal architecture, the crown of the masonry is also oriented, which can be used to create a model of the current state. Experience at a number of sites has shown that photogrammetric surveying is capable of surveying approximately 85-95% of the required extent and content. All measurements are made in 3D.

- **Geodetic surveying** - provides for the completion of those parts of the position and elevation map that cannot be obtained from aerial photographs. (see terrain reconnaissance). At the same time, details of the torsal architecture (architectural elements, structural openings, etc.) are surveyed for the purpose of possible structural and historical research.

- **Creation of final outputs** - from the acquired updated 3D vector data, a digital terrain model is generated, which enables the preparation of additional supporting layers (contour lines, colour hypsometry, longitudinal and transverse sections, terrain slopes, etc.) for the preparation of final outputs of the castle site survey.

- **Presentation and visualisation** - detailed documentation of the site including a geodetic survey is an important step towards understanding and studying the site. However, the presentation of the site to the public also plays an important role, as they can play a crucial role in its protection by changing their behaviour towards the site. For this purpose, reconstruction models depicting the state of the site in one of its historical forms are best suited.

3.5. Procedure for acquiring the photogrammetric model

3.5.1. Planning and tie points

First of all, it is necessary to determine the workflow in advance and identify the important and problematic areas of the object to be documented. For later evaluation, it is also essential to place supporting survey/tie points - that is, points in space that can be clearly identified in the photographs and whose exact position, in reality, can be determined.

A number of supporting techniques can be used for this purpose:

- Signalized points on the terrain around the object to be measured, which are sufficiently visible from the drone, located using accurate GPS coordinates (to eliminate measurement error, their measurement should be repeated at least 3 times and the results recorded

- Targets tobe placed on a clearly visible and stable part of the building. These points can then be identified, for example, between the 3D laser scan and the photogrammetric model, or they can be individually targeted using a total station (here it is particularly important not to confuse their order).

- The third method, which can be performed without specialized equipment, is the use of insertion points, placed in real space so that we are able to use them in the processing phase of the 3D model to simply determine its orientation in space and real size (the photogrammetric model is by the nature of this technology dimensionless and arbitrarily rotated in space). The basis of the procedure is to place all the insertion points in the horizontal plane (e.g. at the same height above the floor, or using a site laser). This will ensure that the model is correctly oriented with respect to the horizontal plane (all insertion points will have a height coordinate equal to or equal to zero). In order to determine the dimensions of the 3D model, all we need to do is to measure the distances between the points in real life (e.g. using a laser rangefinder). For orientation of the model in the ground plane, it is also good to determine the main structure - e.g. a load-bearing wall as the basis of coordinates and then place the insertion points so that at least two of them lie on this wall and it is possible to plot the X-axis by triangulating the other points.

For all insertion points, their marking must be such that they are clearly visible and flawlessly identifiable on the measurement photographs - a number of standardized or improvised intentional targets can be used for this purpose (e.g. in the form of a black and white checkerboard, intermediate circles, or specialized photogrammetric marks). It is also important to mark individual points to avoid confusion when identifying them in the 3D model.

It is necessary to ensure that the tie points are not moved during the taking of measurements and survey photographs - it is, therefore, a good idea to place them on non-moving parts of the building, i.e. not on doors and windows.

The safest practice is to leave the insertion points in place for the duration of the measurement and, if possible, permanently, in case the measurement has to be repeated in the future. This may occur either because not enough photographs are captured during the first shooting session, the measurements had to be interrupted, or if there is an expectation of further measurements, e.g. during construction, so that the models can be aligned to each other before and after changes to the site (including exploratory excavations and probes).

These support points will then naturally appear in the resulting 3D model. It is possible to leave them as such or to retouch them afterwards, as long as this does not distort the essence of the measurement. However, if these points should bother us in the result, it is possible, with careful thought and planning, to take a separate series of photographs of these points, only for the purpose of merging the 3D model, and then remove them and take the rest of the survey photographs without them (or identify and mark these points after the survey photographs have been taken). In both cases, however, it is possible to process the photographs containing the tie points separately and exclude them, for example, from the calculation of the 3D model textures - this way we can achieve that the tie points do not appear in the final outputs at all - but this procedure is highly risky in case of error and makes it impossible to return to the survey later or repeat it.

3.5.2. Taking survey photographs

As described above, the photogrammetric method is based on the automatic machine evaluation of a large number of photographs. The computer must therefore be able to identify as many identical points as possible in the source photographs. If the source images are well taken, then the whole process is virtually work-free and the software outputs a finished textured 3D model after processing the photos without the need for manual work. The only exception and requirement for human processing is then to identify the tie points and verify the correct orientation and scaling of the model, or to define the required outputs (e.g. 2D photo-plans of ground and vertical sections and views of the surveyed object).

However, in order for this automatic calculation process to proceed correctly and with the desired result, it is necessary to follow some simple rules and provide the necessary conditions during the image acquisition:

1) No part of the measured object should be visually changed during the image acquisition - i.e. furniture should not be moved, windows and doors should not be opened or closed, lighting should not be changed, etc.

2) The images should have a sufficient overlap (at least 60% of the same content) and should evenly cover all measured surfaces from all necessary angles. For this reason, it is sometimes necessary to use, for instance, a reduced or increased photographic horizon to capture surfaces that are not visible enough from the human perspective.

3) Since this is a method based purely on the interpretation of the optical record of reality, it is necessary to ensure constant lighting conditions. In the case of exteriors, it is best to plan the photo shoot for the day with the assumption of cloudy skies. Cloudy weather allows outdoor photography to be carried out within a few hours, without having to worry about data degradation due to moving shadows or visual poor quality caused by overexposure of lit and underexposure of shaded parts of the object. The cloudy sky also blurs the differences between the south and north facades and allows the undistorted colour of the objects to be captured. In the case of interior documentation, it is then necessary to ensure that unwanted shadows and reflections do not appear on the documented surfaces during the photo shoot and that the light does not change too much during the entire shooting period. However, the problem here is to ensure natural light, even without direct sunlight. This is mainly due to the fact that the lighting in the

interiors is very uneven due to the size and positioning of the windows. In practice, therefore, we have learned not to rely on daylight when photographing interiors and to shoot only under artificial lighting. Here, the best method is to use a portable LED reflector placed near the camera lens and always illuminate only what I am photographing. The result is an evenly lit 3D model with a uniform level of detail and no daylight-induced contrasts. This can be achieved by blacking out the windows - but it is much more reliable to schedule the shoot during the night. This is particularly advantageous at publicly accessible monuments where it is not necessary to restrict visitor traffic at night. Also, in the case of documentation of e.g. murals, night photography is almost a necessity, so that the resulting documentation is not degraded by uneven light from the windows.

4) Survey images need to be as sharp as possible so that individual identical points in multiple images can be accurately identified. A tripod is usually used to ensure the sharpness of the images during normal photography, but the number of images required (hundreds to thousands) makes the use of a tripod impractical for photogrammetry. Simple discipline during the shooting process and ensuring sufficient lighting of the subject is better. Unless you take the shot just as you step or move the drone, then the sharpness is usually sufficient. However, all blurry photos should be deleted before calculating the actual 3D model so they do not degrade the result.

5) When combining ground and drone images, it is necessary to ensure sufficient overlap here as well. This means starting a series of drone photos at a height of only a few meters so that the difference in angle between the ground and aerial shots is not too great - this will ensure continuity of data and seamless linking of all photos.

6) When taking photos, it is advantageous to use cameras with fixed optics of clearly defined geometric parameters for speed and accuracy of post-processing - combining multiple lenses or zooming during shooting increases the risk of poor image processing in the software.

Guaranteeing technological discipline and ideal conditions is what often differentiates amateur and professional photogrammetric models. As mentioned earlier - data processing technology is now more or less automated to the extent that it can be used without any prior training or knowledge. However, the results can vary considerably in quality precisely because of differences in the quality of the preparation of the images and the creation of the conditions for sufficient quality of the outputs - so the following is absolutely true: any technology is only as good as the people using it".

3.5.3. 3D model processing

A variety of software can be used to process survey images, which are constantly evolving and vary in workflow, quality of output, and, last but not least, price. Therefore, in this section, we will not describe the detailed workflow of specific software, but only give general principles that should be followed when processing images. For details on how to work in specific software, there are extensive documentation and tutorials on the internet.

1) The measured images should be placed and stored on reliable storage of sufficient capacity to allow, above all, fast reading and writing of data (photogrammetry works in the order of tens to hundreds of Gb per model - the speed of data handling is therefore essential for the speed of processing the result).

2) If possible, the images should not be manipulated, enhanced, or edited in any way - this is both time-consuming and risks degrading the data for the calculation. Any editing such as rotating images, renaming them, sorting them into groups (e.g. Canvas, exterior, interior, or images by date), and deleting bad images should be done before loading the images into the software.

3) It is a good idea to keep a basic order in the file structure, i.e. to archive the measurement images in folders that allow a clear identification of the object, when the images were taken, etc. it is also advantageous to keep the files generated by the photogrammetric software in a clearly defined folder outside the photographs to allow subsequent orientation in the project even after a long time at home or by other team members. The proposed directory structure is as follows:

   - PHOTO - photos organised in folders by date and method of capture, e.g. 2021_03_15_DRON, 2021_03_15_Extrier, etc.

   - MODEL - a folder containing all the files and folders generated by the photogrammetric software - both different versions of the model, and powerful data, e.g. parts of the model, auxiliary files containing image registration, etc.

   - EXPORT - a folder for accumulating outputs from the software - 3D models, textures, and 2D renderings of perspective or orthogonal projections

4) It is a good idea to process the 3D model in logical parts - e.g. aerial photos, ground photos, and interior photos should be counted separately and only then combined into one model. This procedure brings faster previewing and allows better control over the result. This makes it easier to detect possible errors in the orientation of the source photos or holes in the model caused by insufficient image coverage.

5) However, it is a good idea to first calculate the preview model to make sure that there are no errors in the model that would require manual correction. Only then should we start the calculation of the 3D model in full quality, because this process takes from one to tens of hours depending on the number of images and the computing power of the computer, and sometimes it is not possible to repeat it several times for time reasons. Preferably, this operation can also be scheduled overnight or over the weekend so as not to delay the normal day's work. This is because the computer is often unusable for anything else during photogrammetry calculations. Therefore, it is also advantageous to work with the data within a network, so that one PC can prepare, filter, and verify the data and another PC can run the time-consuming calculations.

6) It is good to store the different intermediate stages of the calculation or alternative settings of the 3D model in separate files in case an error occurs during processing or it is necessary to revert to a previous version. However, it should be noted that the data associated with photogrammetry can be in the order of tens of Gb.

7) The resulting 3D model usually has a huge amount of geometry and even the most powerful computers are not able to display it. The next step of processing is to simplify the 3D model to an acceptable level - the simplification of the model should be gradual - always to a maximum of 50% of the previous state so that we know in time where to stop. We judge this by the part of the model where we need to keep the minimum level of detail. However, it is also in terms of efficiency to subsequently combine more levels of detail into one model - e.g. use more simplification for building structures than for sculptures, etc.

8) Once the optimal level of geometric detail has been reached (units to tens of millions of polygons), the automatic determination of the texture coordinates (UVW mapping) and the subsequent texture calculation is next. The key here is the resolution of the final output, e.g. in relation to the desired scale of the photo planes.

9) The last step is then to generate the outputs - whether they are point clouds, textured 3D mesh models, or 2D outputs in the form of images, photo plans, or animations.

The processing of a photogrammetric model is not difficult in principle and can be done by a complete amateur, but if it is to serve as a method of exact documentation from which to derive construction plans, design work, or other documentation (especially for heritage buildings). Then it is better not to overestimate your strengths and entrust the data acquisition and processing to professionals who have the necessary experience and equipment (cameras, lights, drones, and other surveying equipment, e.g. total station or laser scan).

Indeed, very often false-positive results are produced. A model prepared by an amateur may appear usable and correct at first glance, but this may not be the case. A 3D model may be incorrectly rotated or scaled, may contain inaccuracies and errors that a quick glance will not reveal, but which may subsequently lead to misleading results in the preparation of drawings or construction projects.

In fact, professionals never rely solely on photogrammetry, but combine its strengths with other measurement methods, such as laser scanning, to ensure the necessary accuracy and reliability of the resulting data.

However, for less challenging objects, preliminary evaluation, or in situations where there are no funds to acquire other forms of documentation, photogrammetry is an invaluable tool not only for documenting cultural heritage, but also for all other geometrically complex objects that are not directly measurable, such as rock formations, sculptures, or landforms.

4. PERFORMING MEASUREMENTS USING TRADITIONAL METHODS

The task of the inventory is to show the condition of the existing building and its surroundings. When starting the inventory work, one should also familiarize with the history of the object, its changes over the years up to the present state, as well as the analysis of historical materials in the object, archaeological works while commencing the inspection of the object and its surroundings. The accuracy of inventory measurements and the method may be different.

The basic traditional methods of making an inventory are:

- Photographic documentation;
- Manual measurement with rangefinders;
- Geodetic methods;
- 3D laser scanning.
- Material inventory
- Opencasts
- Archaeological works

4.1. Photographic documentation

Photographic documentation is an inseparable element of all documentation. On its basis, it is possible to perform an analysis of a historic object. It also serves as a complement to the drawing part. Photographic documentation of historic buildings can be divided according to the frame:

- a frame showing the entirety of the establishment, showing the spatial context of the facility, its exact location, and architectural style;
- a frame showing a fragment of a historic object, e.g. an architectural detail, window or door joinery;

- a frame showing damage to a historic building, e.g. scratches, cracks, biological corrosion.
- a frame showing the opencast (cross-section through a given element of the building) showing the materials, for example, in the ceiling.

All frames should be put on the photo stand plan for quick identification and location.

It should be remembered that basing the inventory solely on photographic documentation results in low accuracy in measurement and disturbance of the scale of parts of the object resulting from the perspective. Photographic documentation should supplement the technical inventory, not be the basis for making technical drawings.

4.2. Manual measurement using rangefinders

This method of inventory management does not require special skills or expensive equipment. The accuracy scale for such a measurement is sufficient to create documentation of the object. Measurements are made using:

- Plastic tape measures;
- Self-retracting metal tape measures;
- Laser rangefinders.

To make drawings (plans), measurements are taken from all walls of the rooms and their elements. Measurements should be made at one height. To make drawings plans, a "string notation" should be used, which consists in reading dimensions from characteristic points on the wall one by one.

Long walls should be inventoried twice to avoid measurement errors. The thickness of the wall should be measured in places enabling a full measurement or section measurement, e.g. in door and window openings. In rooms with irregular shapes, it is also worth measuring the diagonals, which will allow for a more precise determination of the room geometry. Measurements are made with the clearance dimensions of openings and recesses, as well as the height of window sills. Window and door openings should be inventoried as clearance dimensions as well as with its frames.

Manual measurement ends with the so-called inventory note, which is used to prepare project documentation. Manual measurement is the simplest method of making an inventory and is often sufficient to document simple historic buildings. However, it should be remembered that this method is time-consuming and the probability of making a mistake is high. Often, making an inventory using this method may not be fully feasible due to the lack of availability or too high risk.

4.3. Geodetic methods

They are used to measure the geometry of objects and to study deformation and deflection of buildings. Geodetic methods:

- Geodetic inventory with the use of a leveller,
- Geodetic inventory with the use of tachometric devices

The level is used to measure the height of the differences between points located in the field with the use of geodetic staffs set up on pickets. The difference read in this way determines the height difference between the given terrain points. The reference surface for altitude measurements is the zero geoid called sea level. The heights themselves are not measured, but the differences in the heights of adjacent points, thus creating a level circuit.

Geodetic methods are used primarily while:

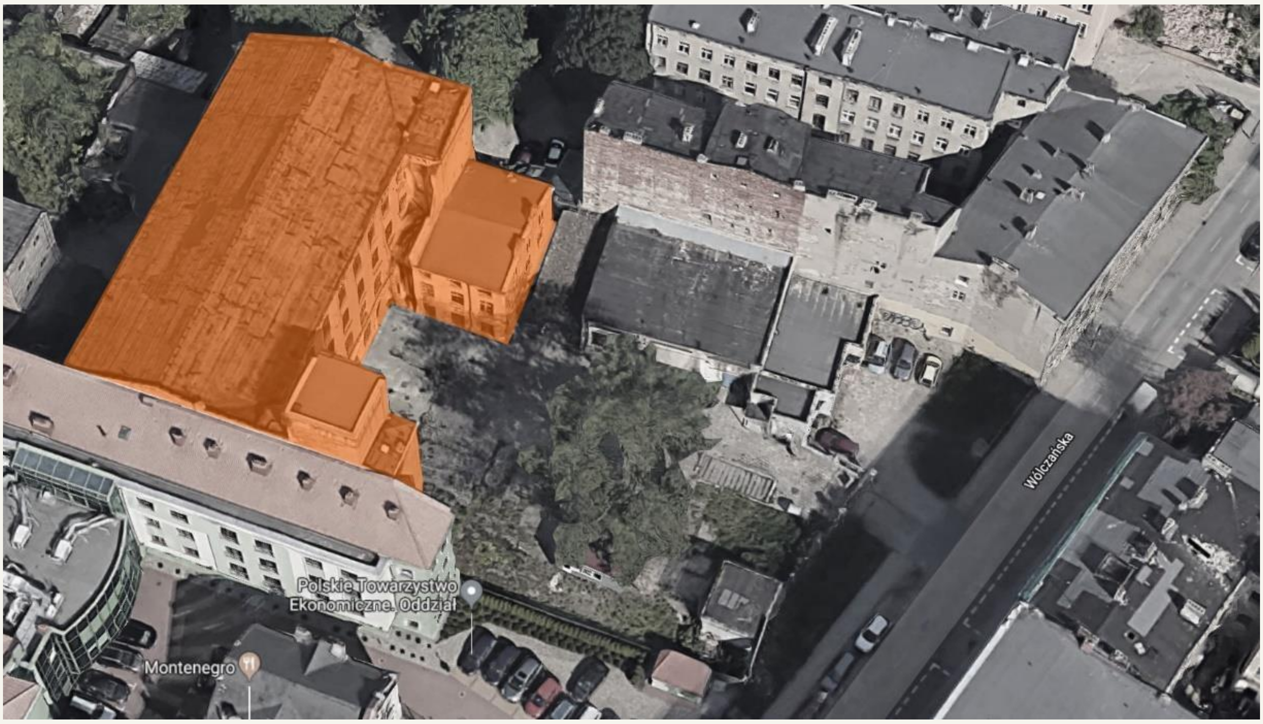
- Preparing maps for design purposes,
- Staking buildings,
- Preparing as-built inventories.

The inventory of an object with the use of tachometric devices is based on the measurement of angles and distances. The measurement of the segment length is possible thanks to the built-in precision laser rangefinder. The distance is determined from the coordinate increments between the position of the measuring instrument and the measured point.

Tachometric devices are equipped with a rangefinder through which a modulated light wave is sent towards a prism or other object. After bouncing off their surface, it returns to the device, where it is intercepted by the receiver - knowing the time of sending and receiving the wave, special software is able to calculate the distance from the object with high accuracy.

4.4. Laser scanning

The analysis of the inventory process based on BIM software will be carried out on the example of a building (old spinning mill) belonging to Filip Lissner`s post-industrial complex of buildings, and then the company „Hirshberg and Wilczyński". This building is listed idividually and within the historical urban layout and cultural landscape of „Wiązowa District" in the Municipal Register of Monuments. This building is located on Wólczańska street 45/47 in Łódź.



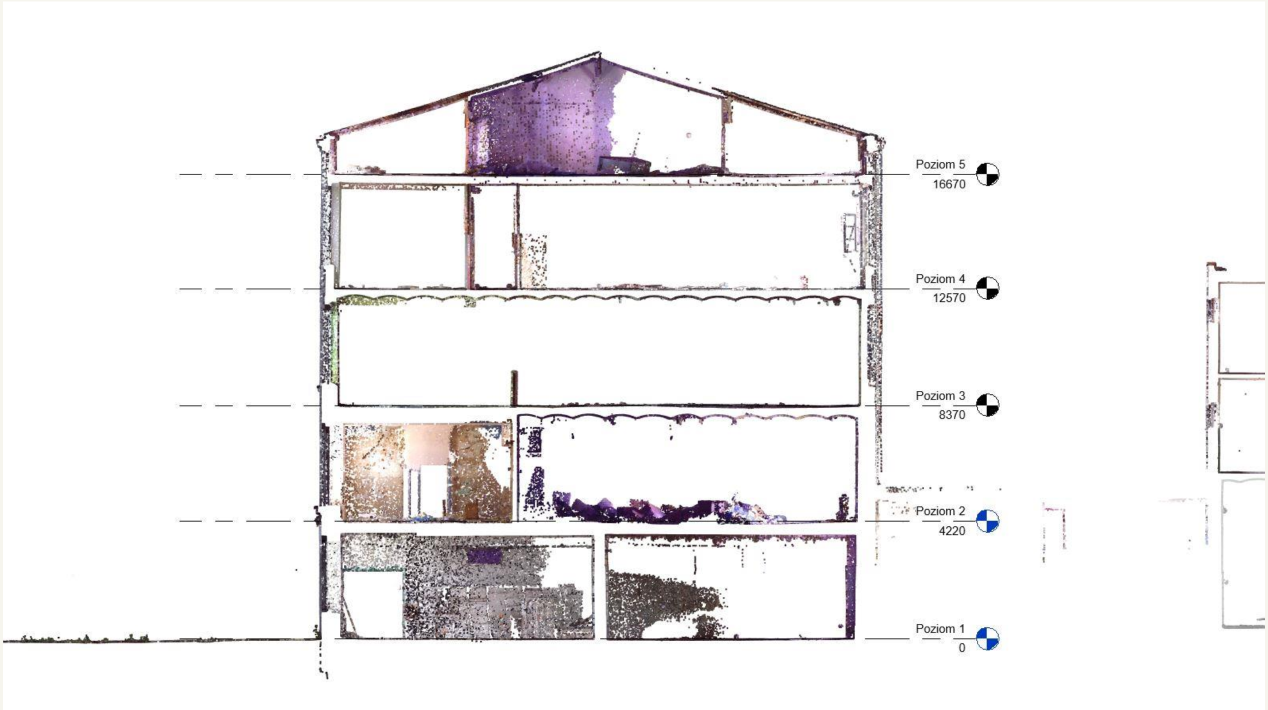
An alternative to the traditional long lasting inventory is the process of creating a point cloud using a laser scanner. The scanning device in a short period of time, depending on size of the object allows for accurate representation of the actual size of the 3D project. The laser does not penetrate the walls, it scans everything around. An important advantage is the ability to set it in a place where no human access is available by using tripods, booms, drone, etc. The laser works non-invasively its operation requires the intervention of a qualified person. The results of the process are the scans which processed on a computer program create a point cloud.

After obtaining a point cloud created by the laser scanning, it is possible to start working in a computer program using BIM technology. The analysis of the modelling process based on the point cloud will be carried out based on Autodesk Revir program. The basis is the appropriate location of the point cloud in the working space of the project – preliminary determination of the storey height, thickness of walls and ceilings and the roof structure. It is possible to read the following parameters from the point cloud:

- wall thickness
- floor thicknesses
- roof slope angles

- size of window and door openings
- arrangement of chimneys and their dimensions
- staircase structure - height, width and depth of runs, landings.

These parameters can be read thanks to the vertical section, which allows to cut the point cloud in any place.]

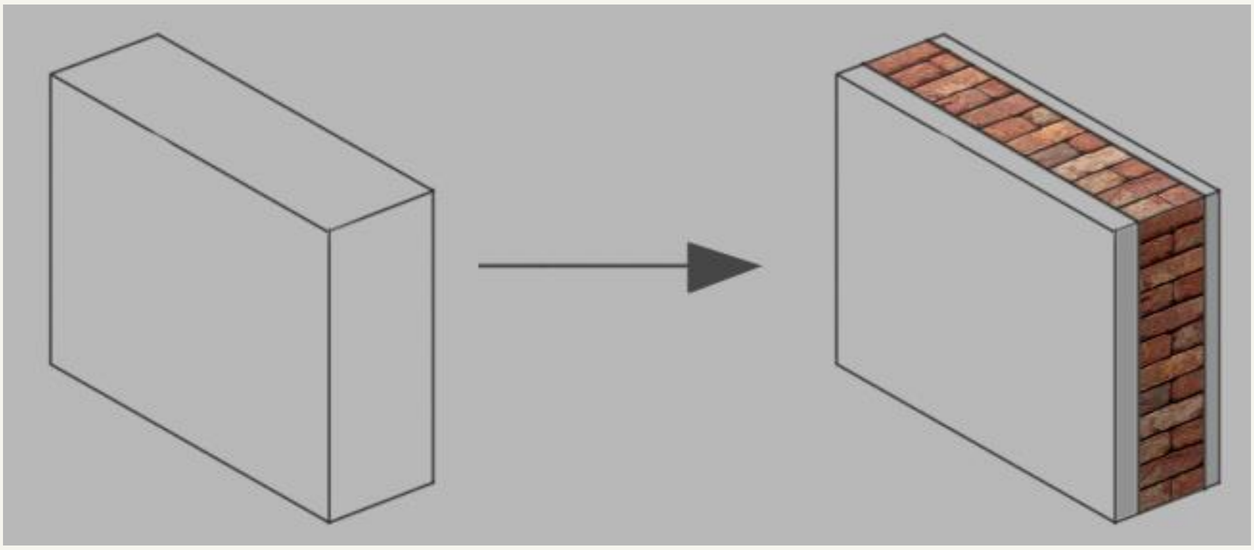


The point cloud introduced into the program allows to read the approximate building area and cubature of the object. It is possible to precisely define the size of rooms and their arrangement on each floor. The model of the structure becomes the basis for its detailing, modelling windows and doors, architectural details and other small elements. On the basis of the point cloud obtained after scanning and reading the characteristic parameters, there is a transition to the initial modelling stage. The Revit software bases its operation on families of elements with variable parameters. The basic elements are walls and ceiling and this is where the modelling process begins. After entering data provided by a 3D model built from a point cloud it is possible to create types of walls and ceilings visible in the model and place them in specific places.

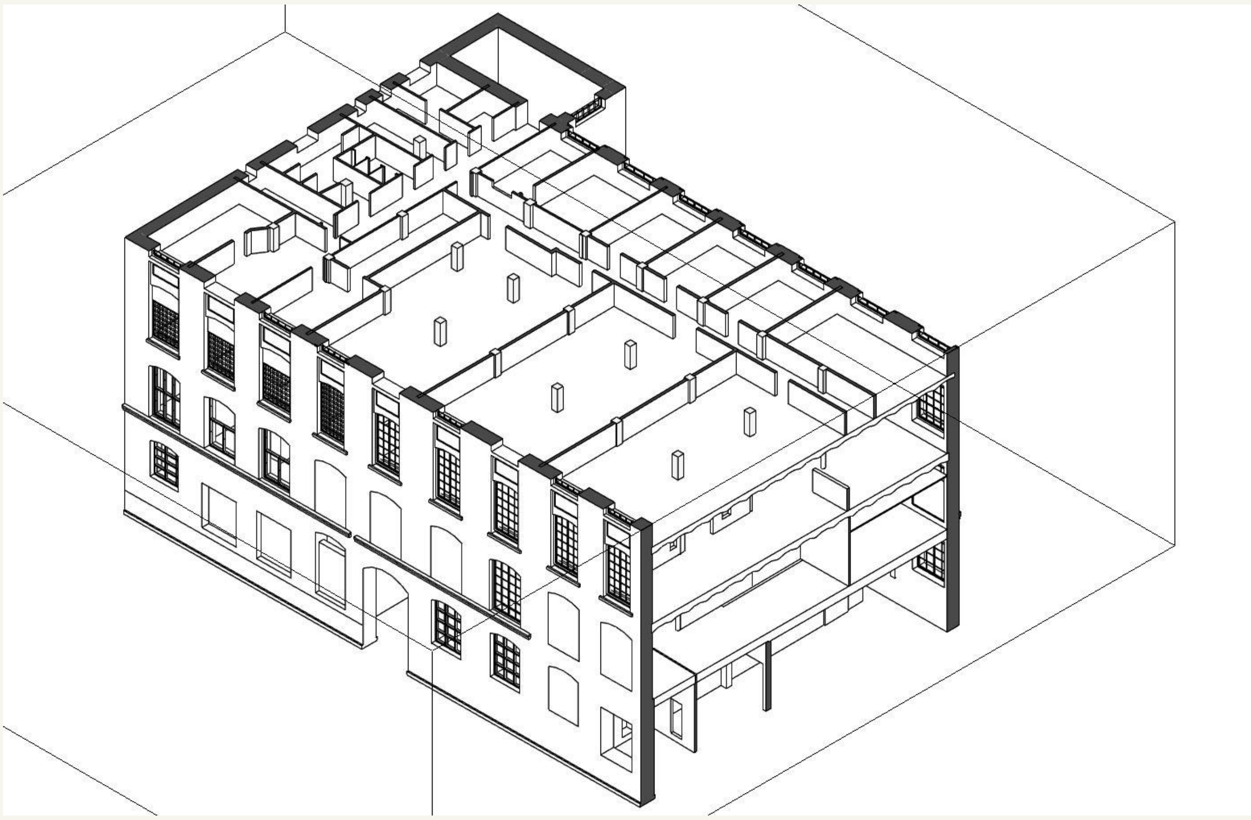
The laser scanner creates also a model of the exterior of the tested object. The Revit software shows the layout of roofs, chimney locations, elevation views and spatial layout of the buildings.

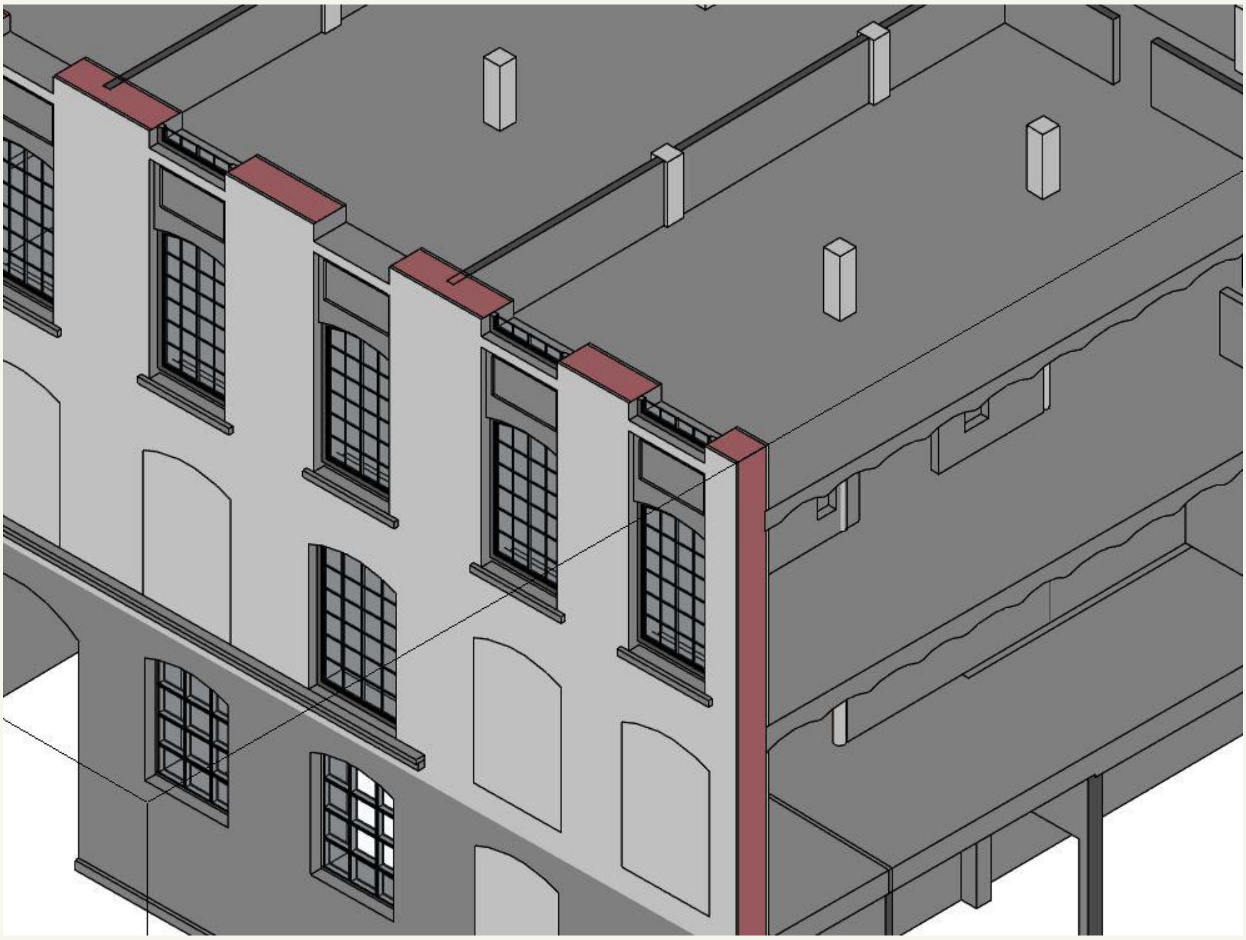
The next step is the introduction of windows and doors thanks to an external family with variable parameters which after loading into the project can be modified to meet the needs of differently sized openings. Proper modelling of successive parts of a historic building is the result of careful observation of the 3D model point cloud and its accurate mapping.

After the preliminary shape modelling, it is necessary to carry out opencast research and chemical tests. The purpose of the research is to define the structure of walls, ceiling, foundation and all elements that cannot be read from the point cloud.

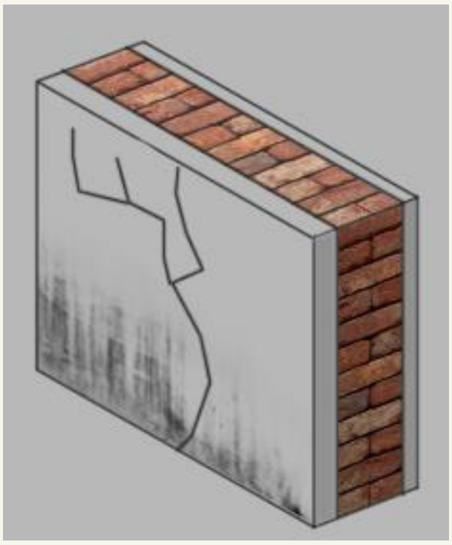


The Revit software allows to modify previously created elements, therefore after performing extensive research of building partitions, updating data should be entered. Due to this the project can be expanded with layer thickness, density, humidity.]

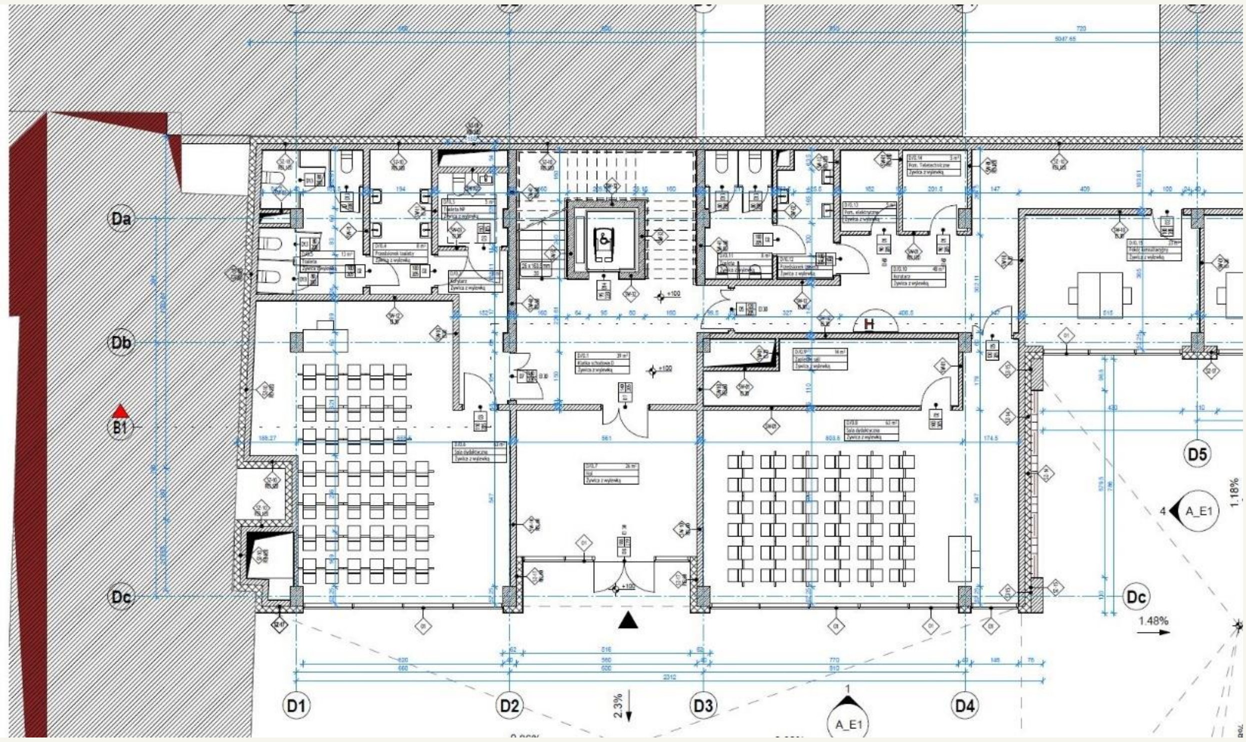




The last element of the inventory process is the analysis of the object carried out on the basis of human knowledge and experience. It consists of carrying out a visual assessment and description of the following parameters: age of structure, architectural style, the need to renovate damaged parts of the building. The object modelled in such way is ready to enter intangible data such as historical values, comments, year of construction and the results of any other research.



The inventory process using BIM technology, in which the working tool is a laser scanner and Autodesk Revit software, makes it possible to examine the object much more precisely compared to traditional inventory. It enables the inventory of objects which condition does not allow human access. It is a tool that improves, accelerates work and gives the basis for further work.]



4.5. Material inventory - opencasts

In order to make technical drawings, i.e. a cross-section, as well as to identify the technical condition of construction elements, knowledge of elements materials is necessary. By making opencasts, it is possible to determine the location of construction elements (e.g. beams), the arrangement of layers in the floor. Material inventory helps to recognize the layout of structural and partition walls, and the position of structural elements. It is one of the most labour-intensive elements of traditional inventory methods, but it gives the most data. No device that could test all the above-described elements has been developed yet.

4.6. Archaeological works

Archaeological research is most often carried out before or during investments located in conservation protection zones established within or near archaeological sites, within urban layouts as well as listed objects. The order and scope of archaeological works results from the arrangements and decisions of the conservator of monuments.

The simplest methods of archaeological work are:

- Survey research - uncovering a small part of the archaeological site by making narrow excavations. During these tests, orthophotography, aerial photography or photogrammetry are performed.
- Surface research - the method of archaeological prospection recognizes the area in terms of the presence of archaeological monuments without interfering with the ground. During these tests, aerial photography, LIDAR aerial scanning, GPS receivers and the GIS geographic information system are performed.

5. TAKING MEASUREMENTS USING 3D SCANNING

These notes provide the minimum information necessary to survey with laser scanner instrumentation appropriately in the architectural field. The choice of the survey method can be guided by considering the dimension of the object, its geometrical complexity and its accessibility for the operator.

The knowledge of the position, size and shape of a building or historical site is a fundamental aspect of the project related to its conservation. The result of a laser scanner survey is the point cloud. This three-dimensional model allows for freely taking spatial measures and obtaining the traditional two-dimensional technical representations (plans, sections, profiles) in CAD formats. Starting from the point cloud, it is possible to get different 3D models to be used through various software and platforms.

These notes refer specifically to the case study of the survey of a building with laser scanner instrumentation to obtain a three-dimensional HBIM model and the bidimensional technical drawings, as plans, sections, and elevations.

The word “survey” defines a set of operations through which to observe, analyse and represent all the components (historical, dimensional, metrical, formal, structural, functional, architectural, etc.) of an object (a single or a complex building, small objects) by using categorizations, codes and appropriate graphical rules. Indeed, it’s a knowledge process that identifies the geometrical features that belong to a specific object. In the Cultural Heritage (CH) field, every object represents a particular case; while the survey methods are the same, what changes is the operational procedures of the work and the instruments used. A good survey requires knowledge of the instruments and techniques, familiarity with software for managing and processing data and the clarity of purposes. An accurate survey is the robust basis for conservation project and further analysis to rely on.

Inspection on the site/check object/selection of the final products (plants, sections, 3D model,…)

Before starting any operation, it is essential to design the survey and to produce a schematic drawing of the area to be surveyed. The first phase corresponds to a project considering both the organization of operations to be carried out and subdivision of the object that has to be surveyed: this is the case of buildings with remarkable complexity. In this way, the body of the architectural object is divided into subparts that are made by restrained dimensions and with morphological or functional recognizable features, taking care to set some specific points where it's possible to anchor all the different parts.

Survey with Terrestrial Laser Scanner

A 3D scanner can be defined as an instrument able to record three-dimensional coordinates of points regularly distributed on the surface of an object, in an automatic and systematic way and with high density. The basic principle on which the different types of scanners are based can be summarised as the projection of a beam or pattern onto the object and the analysis of the signal in return. Scanners are classified according to the distance measuring principle, distinguishing between distance measuring and triangulation systems. This distinction determines the operating range and the attainable accuracy level; thus, it helps recognise the possible range of use of the instrument. Instruments that analyse both time-of-flight[2] and phase difference[3] for distance measurement are called ranging scanners (Fig. 1). In both systems, distance measurement is performed in constant angular steps along predefined azimuth and zenith directions. The control system of the angular movements of the laser beam influences

[2] Pulse Time-of-Flight(ToF) scanners. The pulse of laser light is emitted, and the time it takes for the return flight is measured. Achieving this requires a technologically advanced timing mechanism and a precise mirror and instrument rotation system (vertical and horizontal axis). Pulse scanners achieve high accuracies, typically 2–6mm even at longer distances, generally with less noise. This accuracy is sufficient for most architectural/cultural heritage applications.

[3] Phase-comparison (also called continuous wave) scanners, while offering similar accuracies as pulse systems, calculate the range to the target differently. The phase shift scanner emits a modulated wave. The distance is calculated by comparing the phase of the wave emitted with that received after reflection on the object's surface. This class of instruments has a more limited range than the time-of-flight ones but a higher scanning speed.

both the positioning accuracy of the single acquired points and the scanning speed. Ranging scanners are those generally used for surveying at the architectural scale.

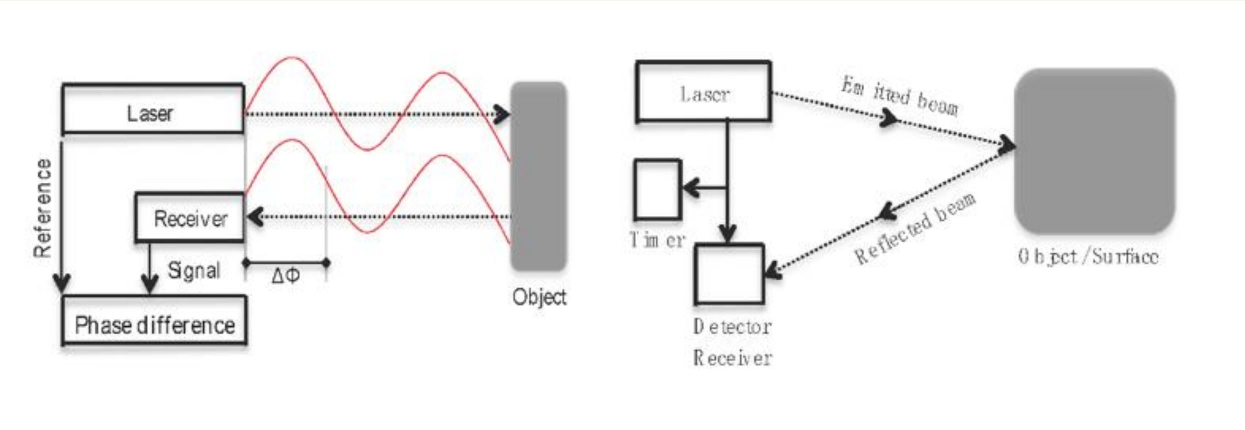


Figure 16 Schematic representation of TOF and Phase Shift principles (López et al., 2018).

The Laser scanner is a surveying tool that does not require contact with the object, so it is undoubtedly suitable when the conservation state of the object requires the absence of physical interaction. From this point of view, it's indicated for surveying the existing buildings. Terrestrial laser scanners can acquire a large number of points in a very short time. Distances and angles are measured in regular networks without the need of other devices, as reflectors for the traditional topographic survey. This technique, compared with other methods, decreases the time spent on fieldwork considerably and can describe completely irregular surfaces.

To carry out a laser scanner survey, it is necessary to choose the right instrument after evaluating some parameters. These parameters are the maximum scanning resolution, the nominal accuracy of the instrument, the nominal and effective range, the measuring range, the acquisition of the intensity of the reflected signal received (reflectivity), the automatic signal recognition, the RGB acquisition (internal or through external devices), the operational autonomy of the instrument and handiness, the ease of use and the availability of software for data acquisition and management. In general, the environment does not influence that kind of instrumentation because the tool works with the different light conditions and with various weather conditions. It is one of the aspects to evaluate to optimize better and project the scanning operations. The instrumentation is generally heavy, and, for extended surveys, it is required the presence of electricity to recharge the batteries. For that reason, the logistical aspect is not negligible.

The result of a laser scanner survey is the so-called point cloud (Fig. 2), or "range scan" i.e. a set of points in space distributed in a more or less regular way (ordered in space). The TOF or phase shift measurements are converted into distance measurements between the point of emission of the laser signal (position of the instrument) and the objects hit by the laser beam. "Range scan" refers to a point cloud acquired from a single scan position. A point cloud can also be a collection of many Range scans.

Figure 17 On the left is an internal view of the buildings and the corresponding view taken from the point cloud, representing reflectance.

There is not only one way to do a scanner survey. Every case is specific and different, but to make a good survey, some steps are always the same. These steps are:

- Design the survey, according to place characteristics and the final products required.
- Acquisition of laser scanner data. Integration with other types of survey, if necessary.
- Data fusion in a raw model, alignment/georeferencing cloud.
- Editing the model, data processing. 2D and/or 3D final products.

5.1. Design the survey

Everything about the survey operation is noted on the field-sketch (Fig. 3) prepared during the inspection or before the survey. The various scanning positions, the extent of individual acquisitions on the object, the presence of the obstacle, the sequence of scans and criteria to align them, ... All this information will be helpful in the data processing phase when importing the scans into the processing software is necessary. The design of the number and position of the scans varies from case to case and is conditioned by several factors, such as the accessibility of the site, the presence or absence of people, the presence of obstacles (vehicles or vegetation) that create occluded areas.

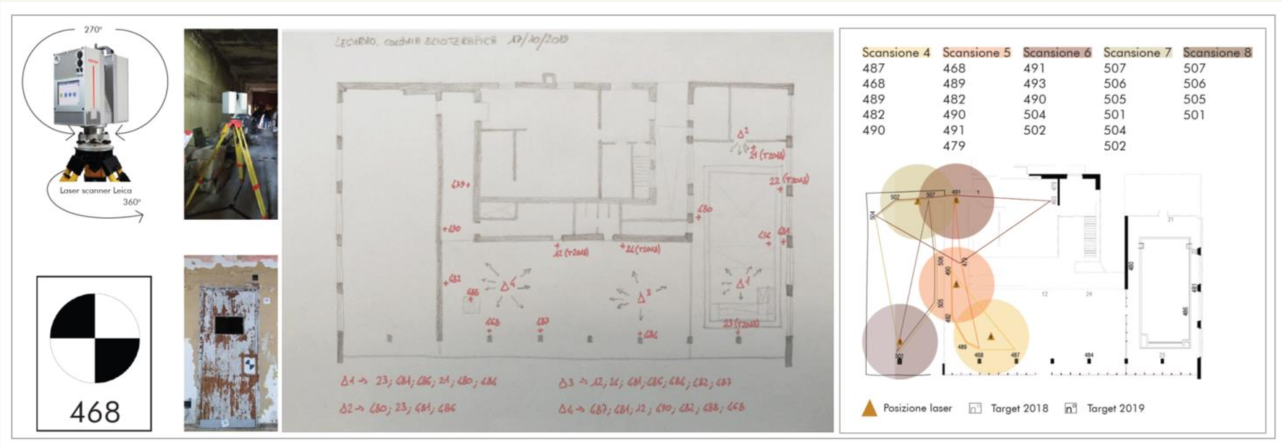


Figure 18 The sketch is an accurate drawing made by hand, in which the measurements and the details are marked on. The sketch is an integral part of the graphic restitution of the building. The operator annotates all the needed data, if possible, paying attention to the sizes, proportions, and information necessary for the following measuring phase. The surveyor has to report all sectioned walls, the elements in plain sight, any level changes, and some data about the materials used. Sketches contain the indication of the building, its location about the general scheme, the progressive number of the drawing, the date of the survey, and the operator's name.

The number of scans changes depending on the size and complexity of the objects. For most situations, a single scan will not produce a complete subject 3D model (Fig. 4). Multiple scans from many different directions are required to obtain information about all sides of the subject. In case of multiple scans, there must always be sufficient overlap between each scan and its neighbour ones.

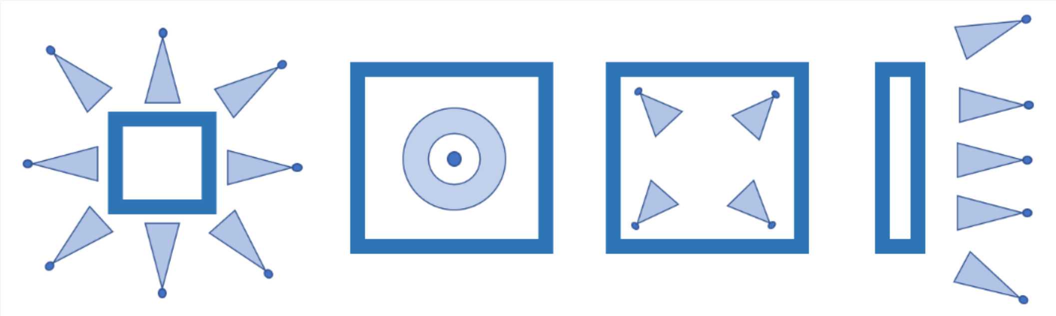


Figure 19 Different shapes objects and corresponding schematic examples of scanner positioning. An all-around object (isolated building, statuary group, ...); an internal space: a single scan may be sufficient, but more frequently, exhaustive documentation is only possible by making more scans; an object with a prevalently linear development (facade of a building, ...). In all cases, when the object develops in height, it is necessary to have scan positions in elevation.

Depending on the shape of the object/building examined, complete documentation must provide for acquisitions at different heights, according to the manageability of the scanning systems and the stability necessary to execute the measurements. Different instrument positions are designed according to the characteristics of the spaces to be measured. When estimating acquisition times, it is essential to remember that the time required to move the sensor is also important, especially when scanning from elevated positions, using scaffoldings or elevator systems, after checking the stability of the support.

The design of the scanner positioning scheme is conditioned by the instrument characteristics, particularly by the acquisition field and the accuracy. The "acquisition field" indicates the detectable area with a single acquisition; it is expressed with an angular value relative to the vertical plane and one relative to the horizontal plane (Fig. 5). The final quality of the point cloud comes from the accuracy of the instrumentation.

The 'resolution' instead indicates the density of a point cloud.

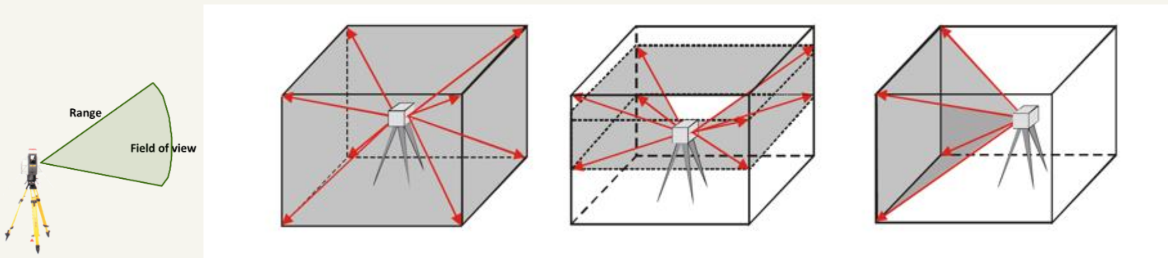


Figure 20 Different field of view related to different scanners: panorama scanner, hybrid scanner, camera scanner.

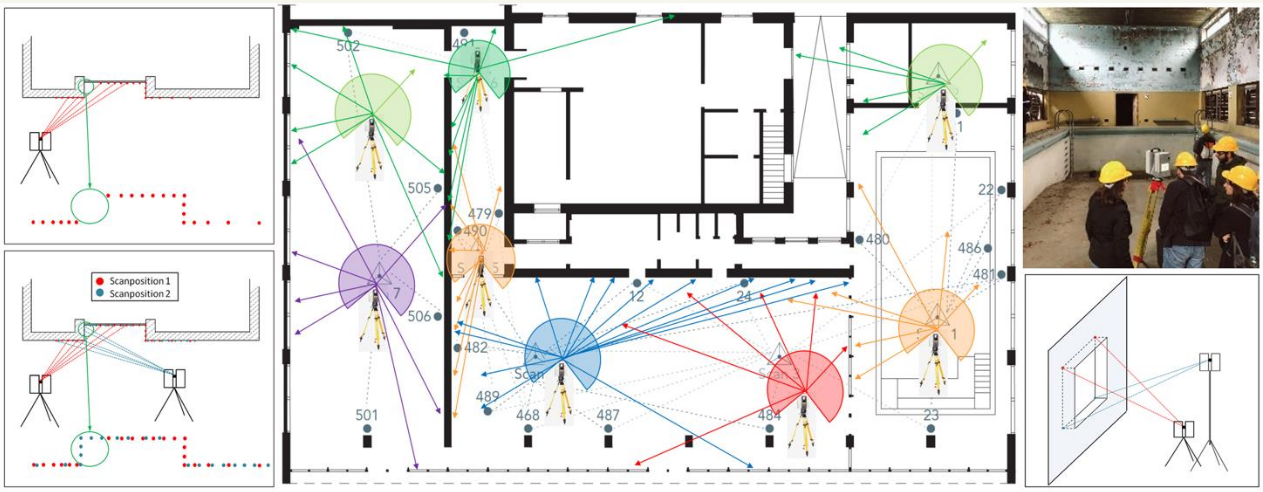


Figure 21 Survey design. A laser scanner can only measure what is visible from its position (in location and height). The scans must be sufficient to ensure complete coverage of the area, avoiding shaded areas and, when possible, without the presence of obstacles. Depending on the laser scanner's angle in relation to the surface, individual areas behind corners cannot be scanned. With the scanner placed intelligently in another location, the shadowed area of the first scan is scanned. The position of the laser scanner should also factor in vertical shadowing effects. For example, scanning a frontage just from a higher scanner position might scan a window ledge well, while an area above the ledge can be a blind spot. Thus, the laser scanner should be moved to different heights to create an image as complete as possible. (the two images left and bottom right: source https://www.laserscanning-europe.com)

The term "resolution" refers to:

- to the space between a measured point and its adjacent ones (the smallest angle increment between successive points, which is a function:
  - of the operator's choice (in most instruments can be manually set by the operator);
  - the acquisition distance.
- The scanner ability to describe small geometric details on the object. It is a function of:
  - the mechanical characteristics of the instrument (motor handling),
  - nominal laser spot size.

The final quality of the scanner acquisition is therefore derived from the combination of angular[4] and distance[5] measurement accuracy. Angular accuracy affects the definition of scanner resolution. Resolution can be defined as the ability of the instrument to detect objects of minimum size, i.e., the maximum density of the point cloud. A reduced angular pitch allows for shorter distances between points in the cloud.

Resolution is also affected by the size of the laser spot. The signal emitted by a scanner is not perfectly coherent and arrives on the surface to be detected with a finite area. Since the emitted signal tends to diverge, its size increases as the distance increases; the more its size increases, the more ambiguously the centre is determined. It is therefore useless to acquire scans with a pitch more minor than the size of the laser spot. The smaller the size of the laser on the object, the greater the level of detail achievable.

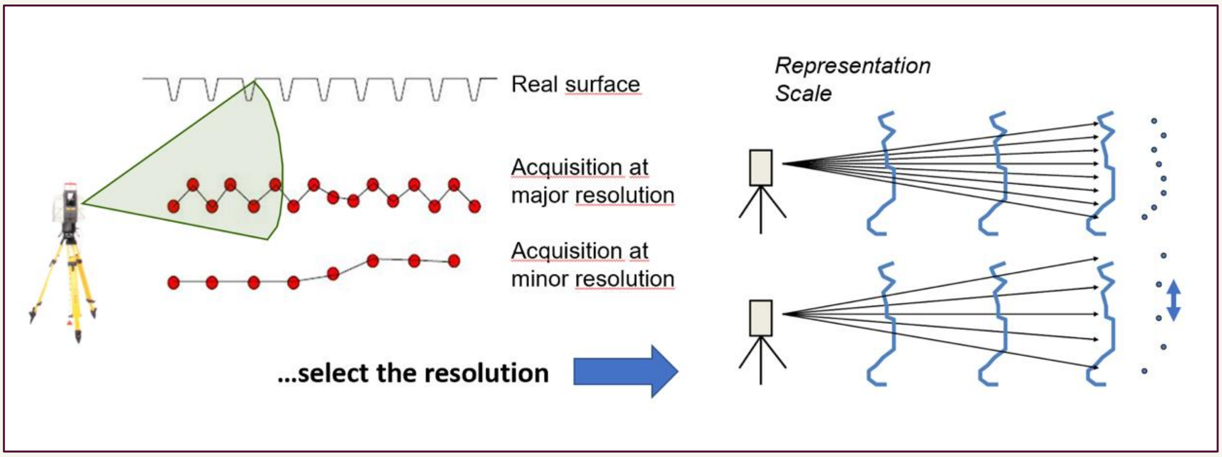


Figure 22 Equal angular resolution set by the operator, corresponding different resolutions on the object to vary the gripping distance; this is a problem because there are different resolutions in the same scan and possible different final representation scales. In this case, the solution is to erase the part of the scan where the quality is too low. The number of scans increase and the time in the field too.

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[4] Angular accuracy: the laser is directed towards the object through the rotation of a mirror or a prism. Knowing the rotation angles in the two directions (horizontal and vertical) and the range measurement is possible to calculate the position of the measured point. Every deviation on the angle measurement introduces an error in the positioning of the scanned point. The angular precision is determined by the characteristics of the adopted mechanical system for the deflection of the laser spot (usual oscillation on a rotation of mirror or prism). Every uncertainty in the definition of the angles brings to an error that corresponds to a shift of the point in a direction perpendicular to one of the distance measurements.

[5] Distance measurement accuracy: ranging scanners measure using the T.O.F. (Time Of Flight) or Phase Shift principle. In these scanners, the accuracy of the distance measurement varies linearly concerning the distance and with values that depend on the type of laser (indications contained in the technical specifications provided by the manufacturer).

In addition, it should be considered that the optimal measurement condition is that of orthogonality: very defiladed scans allow to acquire of larger surfaces, but with lower quality data (lower energy of the signal reflected from foreshortened surfaces, larger spot size for more distant areas, non-uniform range map resolution).

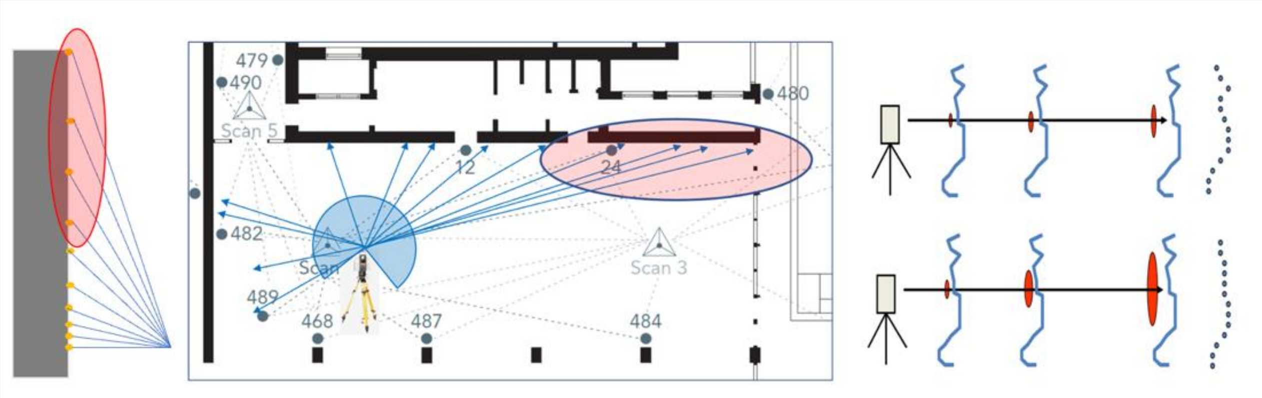

Figure 23 The quality of the laser data decreases with the incidence angle: it is maximum when the laser beam is orthogonal to the measured surface. For this reason, it is essential to discard in the elaboration phase the portion of the data that has poor quality, for its distance from the emitting source and its incidence angle, integrating with a scan made in a better position.

Characteristics of the surface

Systematic errors have been observed, in some cases of considerable entity when compared to the measurement accuracy of the instrument, related to the material and chromatic characteristics of the detected surfaces. In addition, a particular disadvantageous operating condition occurs in the case of acquisitions in the normal direction of highly reflective surfaces or in doing scans with the instrument oriented against the light. Since the points may be either not acquired or affected by gross errors in both cases, it is crucial to design the succession of scans properly, considering these (rare) limitations.

Figure 24 Laser beam behaves differently depending on the surveyed materials. This difference is caused by the chemical and physical characteristics of the objects. Generally, the technical data sheet of the scanner contains the values of reflectivity of some materials. In the CH field, materials can be various and heterogeneous, and the survey design should consider this possibility. A fast and effective method to control the acquired data to avoid alignment and systematic errors is to extract sections and slices in the areas in which particular colours and textures are identifiable.

5.2. Data fusion in a raw model / registration

An essential aspect of using laser scanning data efficiently is the correct registration of point clouds. This step is a prerequisite to easily use laser scanning results in other software (Viewer, Cad, BIM). Each scan is only a part of the whole survey. Each scan must be registered with those around for the final composite point cloud, respecting the degree of precision set during the acquisition phase.

Registration process is required to ‘place’ each adjacent scan in a common context. At the end of the field survey range map is referred to as a reference system with origin in the centre of the instrument and random orientation. Registration steps define the parameters of the geometric transformations required to convert the coordinates of the various single scans into a common system to obtain a unique range map.

At the end of this phase, all scans will result-oriented into a shared coordinate system that can coincide with the scan used as master or another defined a priori during the survey, such as a topographic or cartographic reference system. The registration phase is usually divided into a pre-alignment and a recording end. In the first phase, the alignment can be done using the homologous points of the different scans (pre-signalized or less).

Once the homologous points have been identified (at least three), the cloud is rototranslated, matching the known points in both scans. You can use natural points, such as edges or characteristic points or targets positioned on the scene. In the first case, the precision with which the points can be collimated[6] depends on the precision of the scanner used as well as the scanning resolution.

The second way is to use targets. The targets are signals with these characteristics: black and white (good response to the laser signal); big or small concerning the restitution scale; well distributed on the site; and clearly visible. The use of targets, flat or three-dimensional, guarantees a better accuracy during the detection of homologous points[7]. These detection systems are based on surfaces with known and uniform reflectance (flat targets) or best-fitting procedures of shapes known in geometry and size.

At the end of this first phase, it is possible to refine the quality of the registration of the scans[8].

Laser scanner processing software makes extensive use of automation, both in the signal recognition phase and in the coupling of scans, thus considerably reducing processing times.

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[6] A laser scanner will virtually never acquire a point precisely at an edge. The same edge observed from two different viewpoints will best be represented by a pair of distinct points. Therefore, manual recognition of matching natural points should be limited to establishing an approximate alignment.

[7] Often it is convenient to distribute on the object a large number of targets, which may or may not be measured topographically. Automatic target recognition by the software can replace the manual detection of homologous points.

[8] One of the most popular methods is based on the Iterative Closest Point (ICP) algorithm. This algorithm iterates a rigid roto-translation in space to one of the two clouds, considered mobile, so that it overlaps the other, considered fixed, in the best possible way. This method searches for the best overlap and is the so-called point-to-point method.

Referencing phase is possible also using common surface portions as constraints. This type of constraint is useful when scans are highly articulated areas. The process is conditioned by the shape (and overlay) of the area. If the object has irregularities and complex geometry, the range maps will be able to "fit" correctly. Objects with flat surfaces require greater overlays and/or to consider in the process an important percentage of points, the alignment algorithm (ICP type) is not able to find an unambiguous solution.

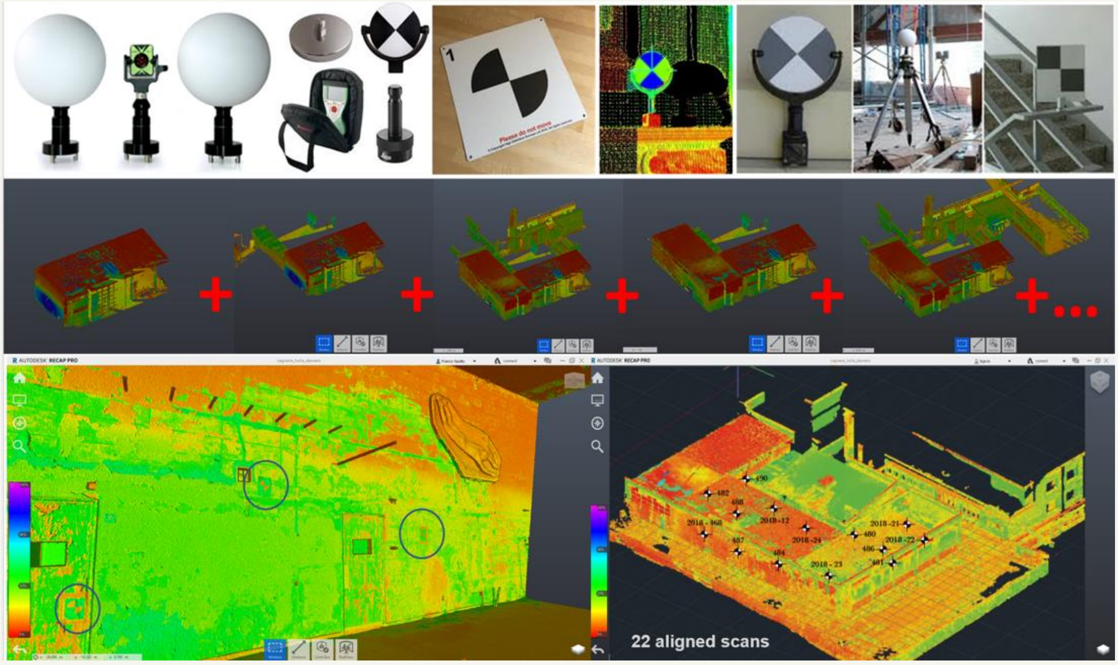

Figure 25 On the top: some examples of targets. ***You can create a unique point cloud using a target, starting from the first scan. This process is usually called 'registration'. The coordinates system corresponds to that of starting scan, if targets (or architectural points) are topographically measured (local or cartographic systems) the whole scan project at the end will be in assigned coordinate system. In any case, the result is a 'big point cloud' that describes the whole area.***

In the alignment of a series of adjacent scans, errors can accumulate that produce even substantial deviations at the end of the range map series. It is essential to acquire an overlapping area between adjacent scans to integrate the undercuts and provide useful geometric information to link the scans themselves.

Each survey is a case in itself. Mixed registration procedures can be used depending on the characteristics of the object and the accessibility of the spaces. Some scans may be bound with targets (known or un-know coordinates) and others through the portion of the surface in common, manually identified.

5.3. Process the data

The interest of those using a laser scanner sensor is to obtain one or more products that will allow them to extract a range of information regarding the object that has been detected. The typical operations of laser data processing are those of data filtering, for the elimination of acquisition errors (outliers and gross errors) and noise present; the elimination of points not belonging to the object (e.g. background points, vegetation, people, ...); possible coloration of the point cloud by means of digital images acquired during the survey operations.

In relationship with the final product, it's crucial to establish how and how far the data has to be cleaned and filtered (data cleaning). In the scans, you can always find points that do not belong to the object, and that must be eliminated[9] (things in the background, trees, people, etc.). The result is a complete point cloud of the object that represents the starting point for the creation of any product aimed at the end user.

Usually, these steps are conducted by scanner software. Software is an integral part of any scanner system. Not only does it operate the scanner, but it must also efficiently store, manage, process, and display the point clouds captured during the scanning process. Laser scanner software is generally designed to handle large volumes of data (the point clouds) and allow real-time viewing/editing operations.

The laser data is a way to 'communicate 3D' of great impact, and it is possible to improve the realism by integrating the colour information to the cloud of points acquired. It is possible to incorporate the laser data with the radiometric data of the object mainly in two ways:

- using a laser instrument that already has an RGB sensor inside (colour applied in real-time); or using an external camera mounted on a calibrated support (colour applied in post processing in a semi-automatic way).

- using images of the object previously oriented photogrammetrically and re-projecting the colour on the point cloud. This mode is certainly less expeditious because it requires a photogrammetric processing step.

[9] Data cleaning and filtering involve removing extraneous scan data from unwanted elements, such as people, vegetation, obstacles, details that do not belong to the data object through windows, etc. This operation is essential because it reduces the size of the data set.

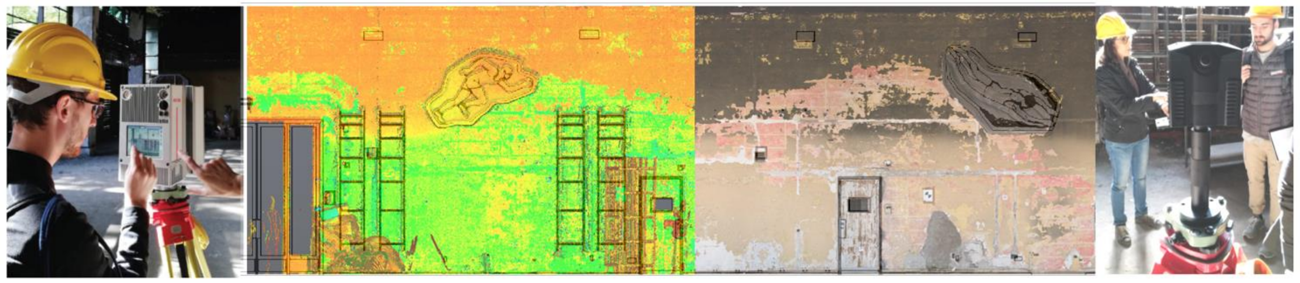

Figure 26 Applying colour to the point cloud makes the final data more interpretable. ***It is certainly indispensable in all those cases where the project cannot disregard the correct recognition of materials and their state of degradation. On the left the Leica HDS7000 scanner and the point cloud; on the right the Istar camera and the result of the application of colour to the point cloud.***

Data formats

Most software packages export and import text files containing x, y, z coordinates, intensity data, and any colour (RGB) information for laser scan data. Currently, two formats allow data to be exchanged in a point cloud format, retaining information in addition to coordinates the *.LAS format, designed for airborne lidar data, is also used for ground scanning; and the *.E57 format.

For derived products, other exchange formats[10] are available (potential products derived from laser scan data include: triangular mesh model; textured mesh model; panoramic imagery; ortho-images; DTM and DSM; CAD data - plans, elevations, sections, models; BIM models).

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[10] The following file formats are examples of commonly used exchange formats.

- E57 – ASTM, ASCII, image data, gridded and random points
- LAS – ASPRS, ASCII, fixed record, mainly for aerial
- LAZ – a compressed version of LAS
- PTS – ASCII, unified data, one coordinate system only
- PTX – ASCII, multiple scans with transformation information for each
- TXT – ASCII, x,y,z point cloud For triangular mesh data:
- OBJ – Wavefront, ASCII, surfaces, primitives
- STL – 3D Systems, ASCII and binary, solid model creation, 3D printing
- PLY – Stanford, ASCII or binary For DTMs:
- TXT – ASCII text, gridded or random
- DXF – Autodesk, ASCII; DWG – Autodesk, binary

5.4. Production of the final product

After having carried out all the preliminary treatment operations, it is possible to proceed to the creation of the final product. The products that can be obtained today using laser technology can be of various types. The point cloud is a survey data that, as satisfying it is, it does not represent planimetry, sections or models. To obtain technical 2D representations (plants, sections, profiles, facades, etc.) or 3D models it's necessary to proceed with the laser data's elaboration with dedicated software.

Today there are several programs with which to visualize and process point clouds. Essentially, it is possible to divide these programs into four categories:

1. View/editing software.

2. CAD software.

4. Reality based Modelling software

3. Parametric-object oriented software – BIM software

What software should I use? It depends on what my needs are.

View and editing software

This typology of software offers the possibility to view, navigate, interrogate and edit the point cloud data. They allow users to perform a "virtual direct enquire" of the survey data to extract measures, sections and 3D elements or simply view the model, according to the operational needs, avoiding further on-site inspections and survey integrations. User interfaces are usually intuitive and friendly for the visualisation part, with simple zoom, orbit and pan commands.

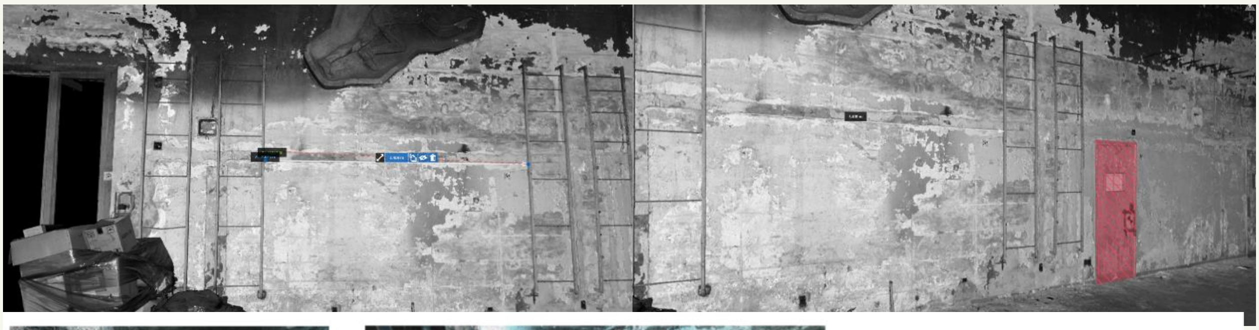
Most of the considered software offer also basic editing capabilities, such as extraction of cross sections and subsets of the point cloud, possibility of cleaning the unwanted points, manual segmentation tools and export in various formats. When present, advanced editing capabilities might include noise filtering algorithms, automatic object recognisance, automatic extraction of cross-sections and profiles, cloud-to-cloud alignment and cloud-to-cloud and cloud-to-mesh distances computation.

Most of these software work with both structured and unstructured point cloud and are able to display the whole point cloud and, if present, the single scan station cloud in a scan-cantered perspective. Some software, as Autodesk ReCap and the Scalypso suite are standalone view and editing software that can work also as connectors for the use of the point cloud inside the most common CAD software.

As recent development, point cloud visualisation and editing web platforms are growing in number and offered possibilities to the final user, both as standalone products or as part of commercial suites: this kind of solution enables users to consult and work on survey data through web browser.

Table 1 Not exhaustive list of possible software and web platforms

Software/Platform	License	Web	View	Editing	Advanced Editing
Autodesk ReCap	Commercial	X	X	X	
Bentley Descartes	Commercial		X	X	
Bentley Pointools	Commercial		X	X	
CloudCompare	Open source		X	X	X
Leica Jetstream Viewer	Commercial		X		
Leica TruView	Commercial		X		
Meshlab	Open source		X	X	X
Pointfuse	Commercial		X	X	
Scalypso	Commercial		X		
Cintoo cloud	Commercial	X	X	X	
Flyvast	Commercial	X	X	X	

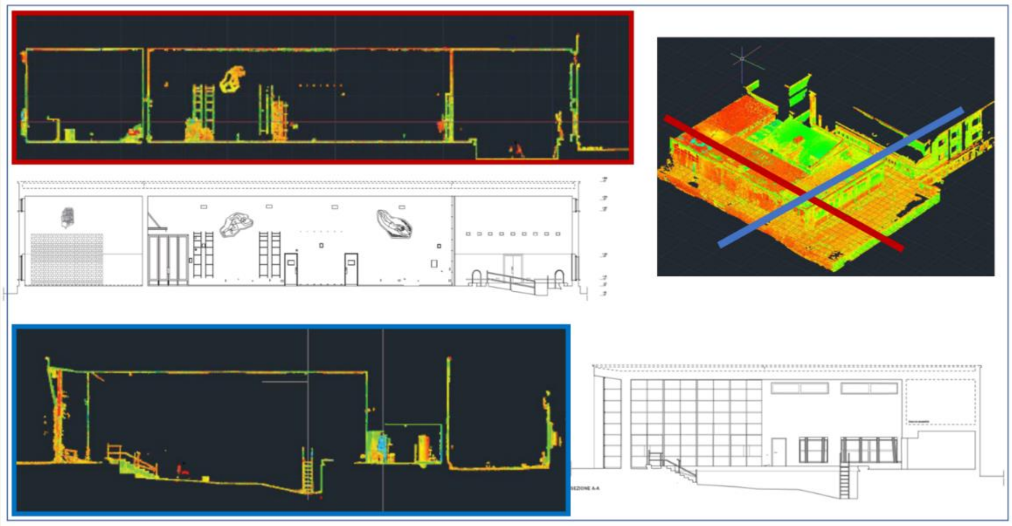


CAD software - Bi-dimensional drawing

For this document purposes, as Computer Aided Design software are here intended the software used for bidimensional vectorial drawings. The CAD software family is very broad and can include also 3D modelers and advanced suites for the manufacturing industrial sector. CAD software are very common in the sectors that work and produce technical vectorial drawing, from AEC (Architecture, Engineering and Costruction) to city planning and mechanical manufacturing.

They are commonly used for the vectorialization of three-dimensional survey, as the 2D technical drawing is still an important deliverable for the architectural field thanks to its immediate interpretation and high metrical precision. Vectorialization produces a drawing of a selected view (a plan, a section, an elevation) of the surveyed building based on the point cloud through the interpretation made by the drawing operator: this is necessary because the data from survey, even if properly aligned, filtered and elaborated, might have shadowed areas, residual noise or unclear parts, that the operator is able to correctly understand in their geometry and reconstruct in the drawing making recognizable hypotheses.

The process of drawing on the point cloud relies on the possibilities offered by the various software to create section and slices (technically, visualize subsets of points according to their position) of different thickness to represent correctly the architecture according to the visible points, integrating with reliable hypotheses the portions where data is missing or unclear. The bidimensional CAD representation produces detailed drawings and lightweight files, if compared to the point cloud or mesh but, of course, representation is constrained to the chosen projection plane, that should carefully defined according to the needs of the final user of the drawing. Nowadays, most of the CAD software are also able to work also in 3D environment as modellers.



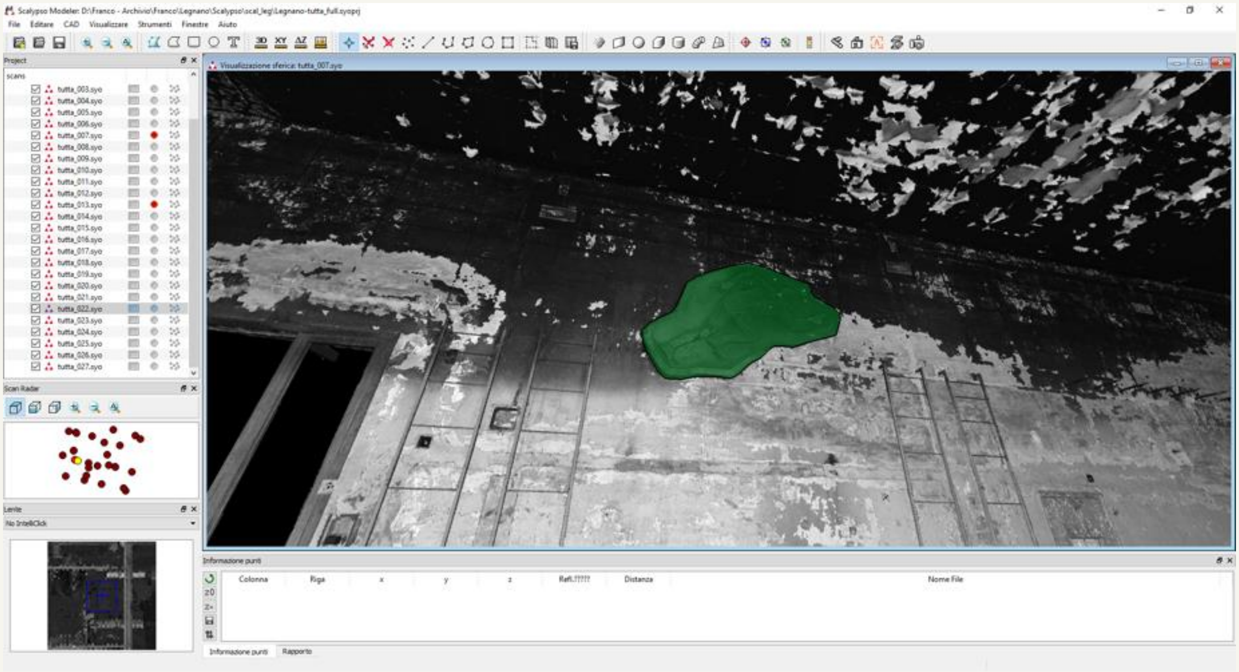
Reality based Modelling software

It is possible to identify two main approaches to the 3D modelling of the point cloud: the use of mesh and the use of NURBS geometries.

The mesh can be created with automatic algorithms directly from the point cloud, after a phase of cleaning and filtering that removes noise and disturbing scanned objects, that would interfere with the creation of the mesh, leading to undesired results. The mesh model is obtained "connecting" the points creating triangular surfaces, and its definition can be comparable with the one of the point cloud if not decimated. Usually the post processing of the mesh is time-consuming and complex.

The approach based on NURBS (Non Uniform Rational Basis-Splines) is generally manual and relies of the ability of the operator to cut the point cloud in specific position in order to extract profiles to be vectorialised and to be used as generative geometry for the surface and solid modelling. This process is expensive in terms of time and the accuracy of the final result is related to the experience of the operator, the dedicated time and the effectiveness modelling tools offered by the software; moreover, each modelled element is generally unique and it is difficult to be adapted to similar ones, so, generally, the process starts again for each component. In the field of Cultural Heritage this operation is particularly challenging because of the complexity of geometries and of decorative apparatus. A significative tool to be mentioned is the NURBS parametric modelling, generally called "parametric-generative modelling", consisting in a partial automation of the process: the extraction of generative vectorial geometries it is still manual, but the creation of surfaces and solids is made by an algorithm and varies according to the input geometries; this process allow to significantly reduce the time dedicated and "reuse" the generative algorithms changing the input geometries. For the Cultural Heritage field, with unique elements that in some cases can be referred to similar geometrical rules, it is a proficient approach. As for the previous case, the final accuracy of the model and the deviation from the survey is to be verified.

For NURBS modelling, the final result is an idealized model based on a discrete selection of real-based geometries (obtained through vectorialisation of the point cloud) that fits with local accuracy the point cloud, according to the amount of generative geometries in input and the ability of the software in performing the interpolation.



Parametric-object oriented software – BIM software

A specific category of software is the parametric-object oriented modellers, that usually offer the possibility to enrich the models with pre-determined and custom information: it is the case of the well-known BIM software.

Usually, these software refer to embedded libraries of parametrized architectural elements, mainly based on the standardized objects used in the new construction field. The modelling strategy consists in adapting the standardized elements from the library to the real architectural ones, using the parameters (as height, diameter inclination etc.) to modify the element in order to obtain the best fit on the point cloud.

This approach is quite effective in terms of speed and result for the modelling of new construction, based on standardized architectural elements, but might present some critical issues in the Cultural Heritage field according to the already mentioned complexity of the shapes, that might require the creation of custom libraries, the increase of parameters or the in-place modelling to obtain a precise description of the architectural shapes. Aside from the modelling issues, that have to be considered according to the level of detail that is required for the representation of the survey, the real value added by these software is related to the embedded possibility of managing information through the geometry and the possibility of produce 2D drawings that automatically update according to the modifications on the model;

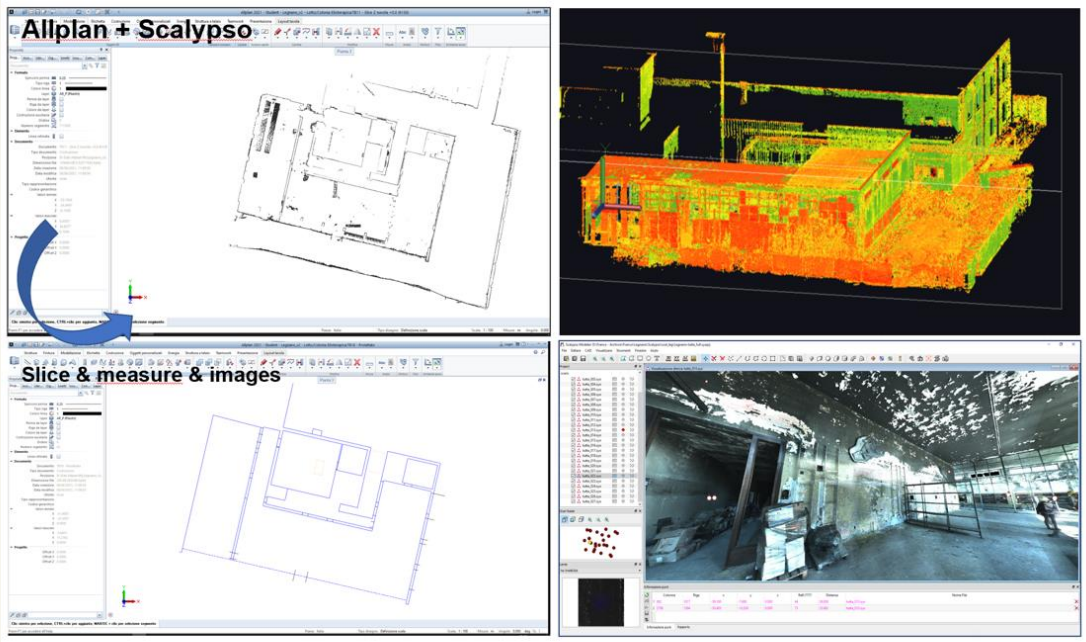
in scientific literature and professional practice in the HBIM field, the parametric-object oriented software are mainly preferred for their ability of manage data and linked information, rather from the possibility of accurate geometrical description.

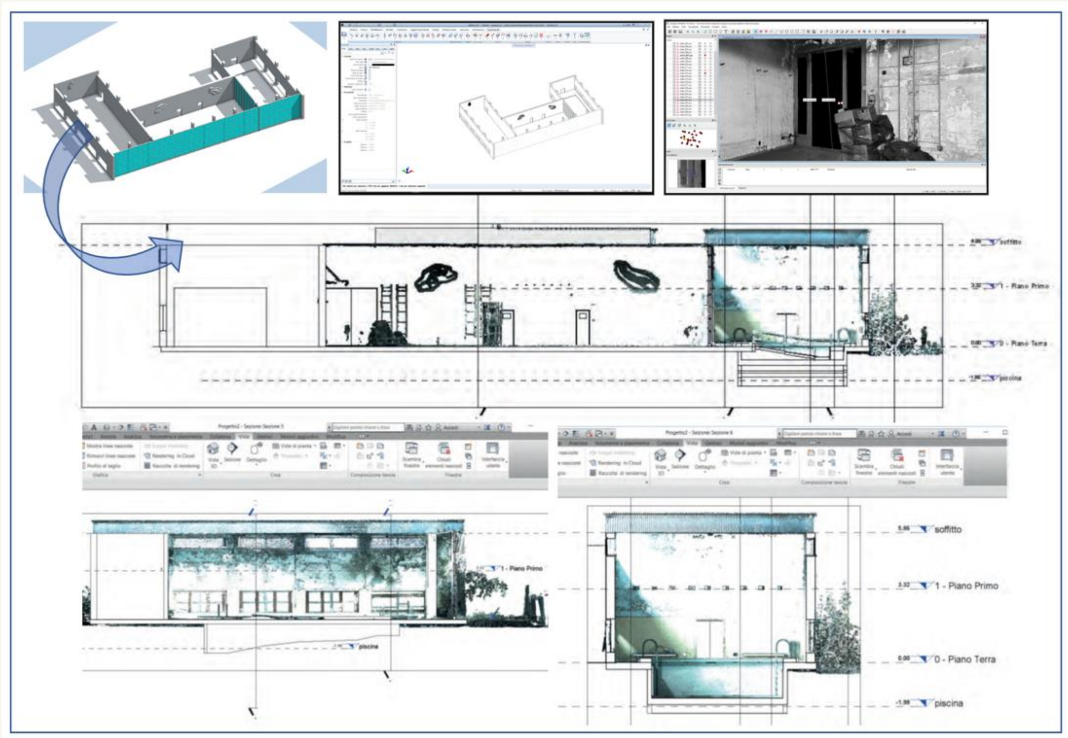
Nowadays many researches are focusing on the construction of specific object libraries for covering the most possible amount of Cultural Heritage cases, facing the difficult problem of the variability and uniqueness of the heritage architecture, that reflects also in the need of specific property sets for the restoration and maintenance needs of every single, specific architecture. Most advanced experiences use external databases and external modellers in order to adapt of the complexity of the case study.

Table 2 Not exhaustive list of possible software and their features

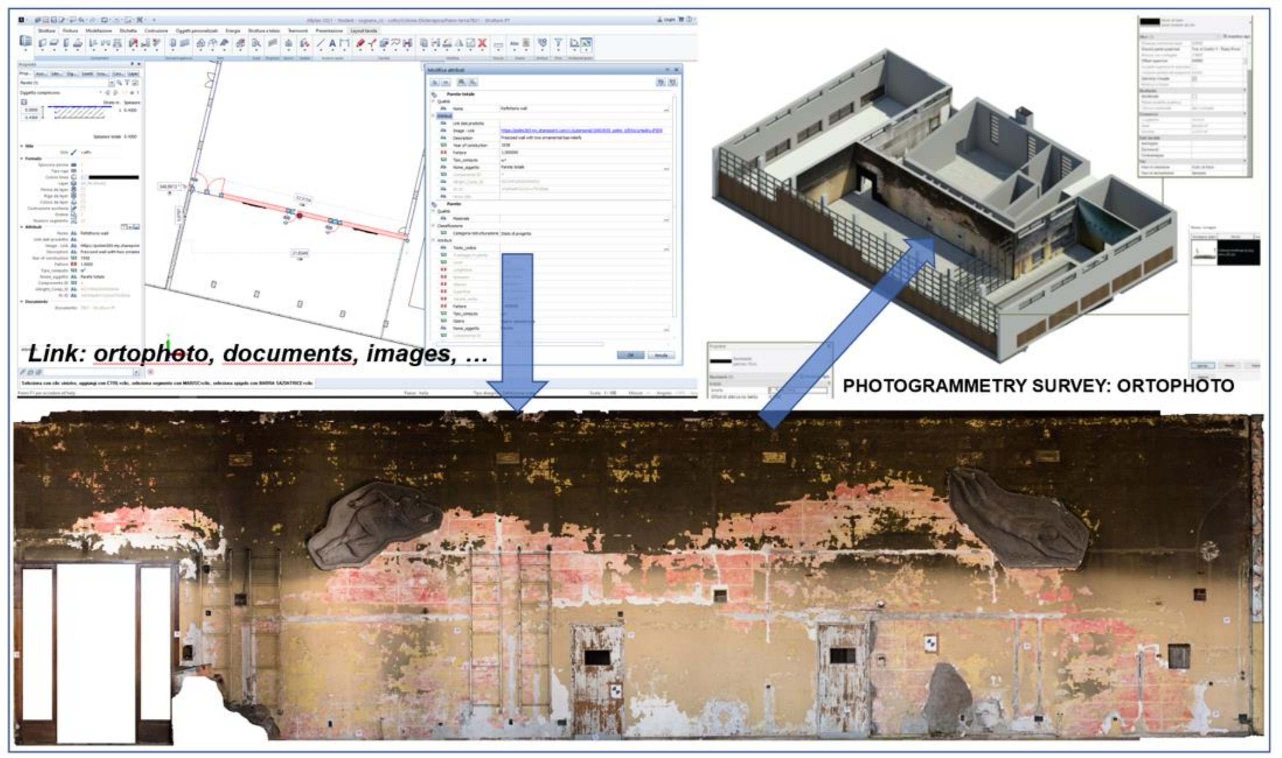
Software	License	2D	3D	Parametric Generative	Param. object-oriented	Information management
Autodesk AutoCAD	Commercial	X	X			
Autodesk Revit	Commercial				X	X
Graphisoft Archicad	Commercial				X	X
Nemetschek Allplan	Commercial				X	X
McNeel Rhinoceros	Commercial	X	X	X		
Trimble SketchUp	Commercial		X			
Bentley Microstation	Commercial		X			
FreeCAD	Open source	X	X	X		

Thanks to the integration between Scalypso and Allplan is possible to transfer in the BIM environment the precise geometrical data taken directly from the point cloud, as vectorial data (points, lines, polygons) useful for the drawing and modelling and complete slices.

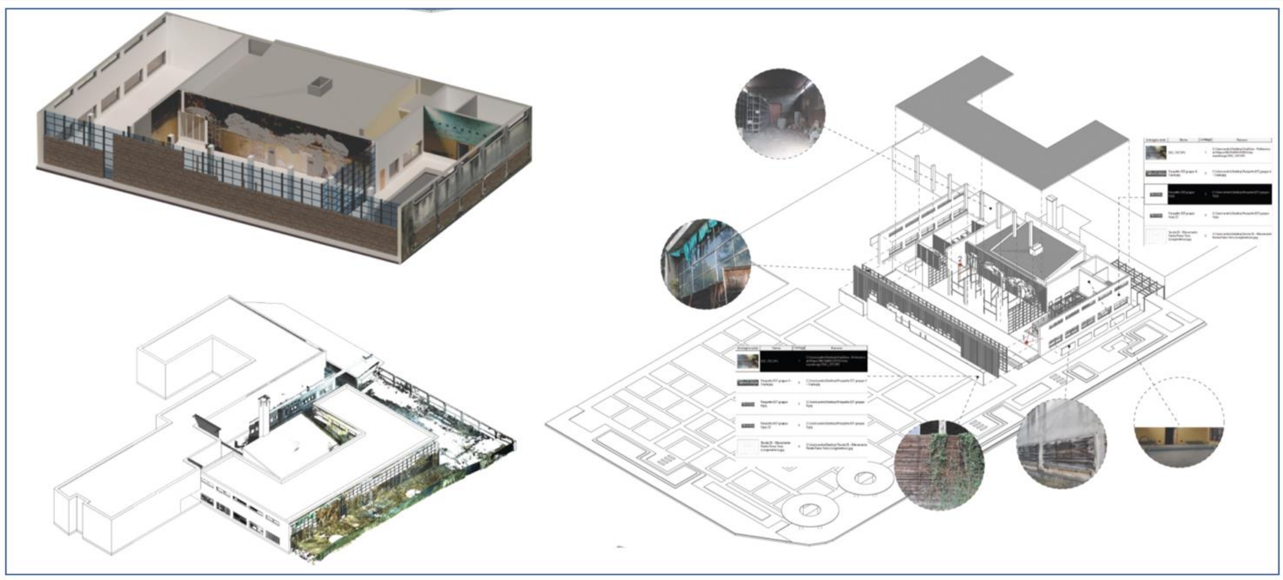




Through this connection is possible to precisely build the BIM model with the in-place modelling, sharing the same reference system with the point cloud. Once the model is realised, is possible to easily extract all the needed 2D data. Modelling structure is not enough, and it is mandatory to collect all information coming from the historical investigation, material analysis, and so on.



Additional material, as ortophotos and degradation mapping can be attached directly to the geometry. In the end, the 3D mode, the 3D model is the accurate 3D representation of Colonia and it collects all data indispensable for the conservation project.



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6. WAYS OF SAVING THE RESULTS

Introduction

The objective of this chapter is to understand the main ways of managing and saving data in the HBIM flow, considering factors such as: nature of the data, conservation issues, accessibility and possibility of reuse.

It should be noted that we will not dwell on the characteristics of the data processing phases of an HBIM product, but rather on the types of data produced and used.

Brown (2006) defined file format as *'the internal structure and encoding of a digital object, which allows it to be processed, or to be rendered in human accessible form. A digital object may be a file, or a bit stream embedded within a file*'.

6.1. Notes on the HBIM workflow

In the HBIM workflow we find ourselves in the presence of some fundamental steps that for their characteristics produce elaborates, data and materials of a specific nature and format.

Let's see at a schematic level the fundamental steps of an HBIM flow and then better understand how to treat the data produced.

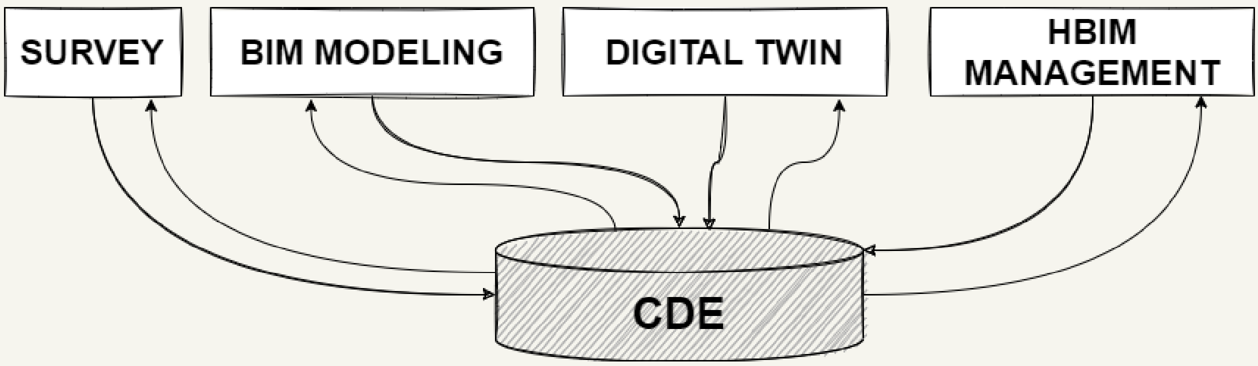

Figure 27 HBIM workflow

6.1.1. Survey

In the survey phase there are moments of data acquisition involving 3D laserscan, cameras, GPS detectors.(**Błąd! Nie można odnaleźć źródła odwołania.**)

As for 3D laserscans, the possible outputs are many: from point clouds to three-dimensional meshes. All this data are archived on the Common Data Environment (CDE) in cloud.

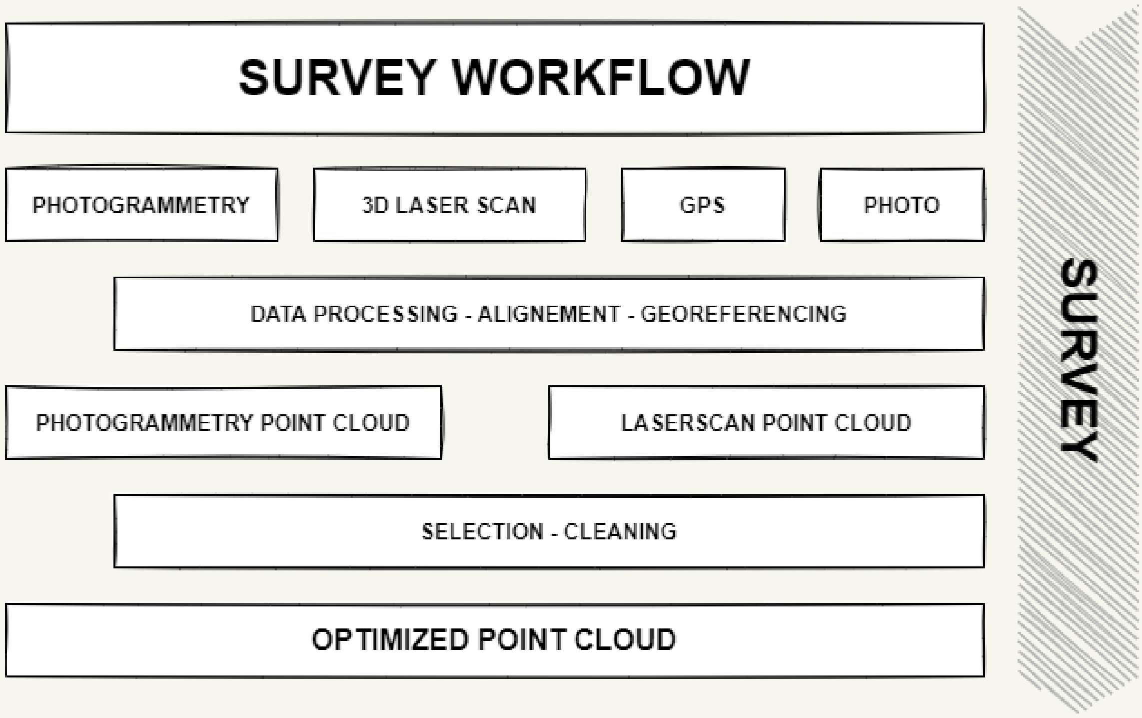

Figure 28 Typical survey workflow

Figure 29 Type of survey data

6.1.2. BIM

Once detected and processed, the result obtained is transferred through appropriate software tools, or through specific plugins, to BIM authoring software for modeling.

It is a fundamental step that must be managed with care and experience. From the cloud of detected points you can get to the BIM model by managing the conversion into suitably optimized surfaces. From the mesh imported into the BIM authoring software, we move on to a three-dimensional parametric model that can be enriched with graphic and non-graphic information.

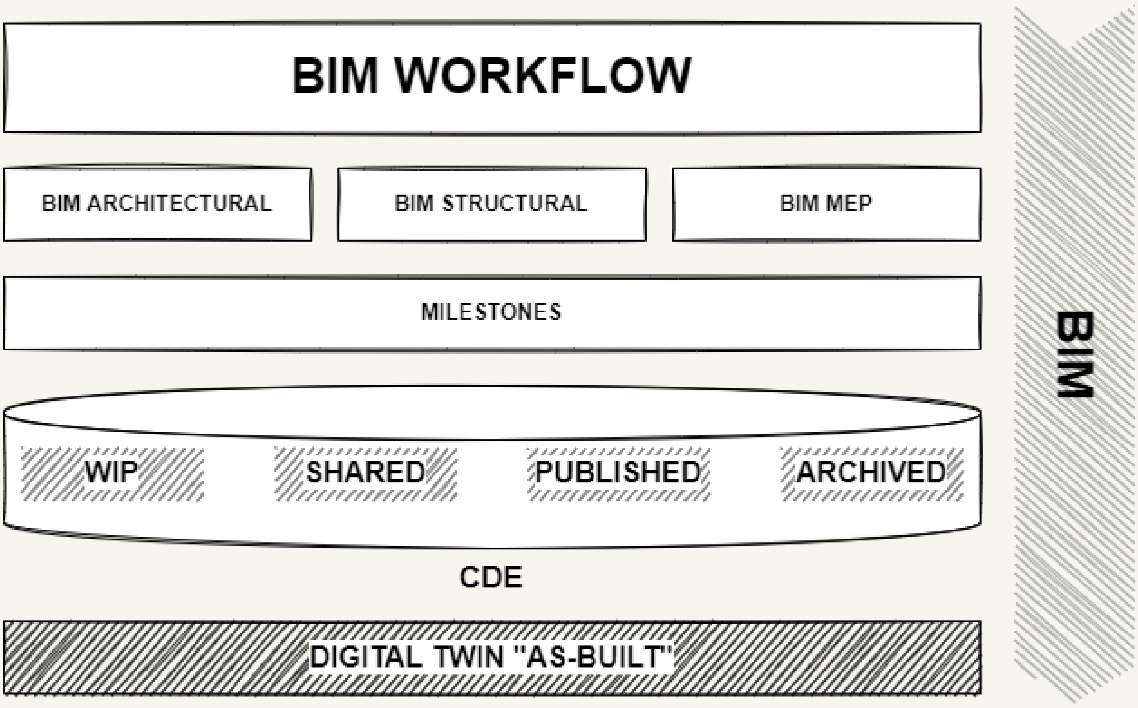

Figure 30 BIM workflow

6.1.3. Digital Twin

The resulting BIM model, what in cases of greater detail is called "as-built", can then be passed to the management phase, where the information present is used, any missing data is completed, further information is added.

The Digital Twin is therefore outlined as a parametric BIM container of information relating both to the geometry of its component objects and to external references (hyperlinks) to multimedia repositories.

Figure 31 from laserscan survey to HBIM model and analysis

6.2. Types of data

The nature of the data processed in a Heritage BIM project can essentially be of the type:

- Raster[11]
- Vectorial[12]
- Text[13]
- Multimedia[14]

For an official list of file formats, please refer to what is published by the IANA[15] (https://www.iana.org/) or even to what is present in Wikipedia.[16]

Raster

***raster graphics**, also called **bitmap graphics**, a type of digital image that uses tiny rectangular pixels, or picture elements, arranged in a grid formation to represent an image. Because the format can support a wide range of colours and depict subtle graduated tones, it is well-suited for displaying continuous-tone images such as photographs or shaded drawings, along with other detailed images.*

- All data deriving from photographs (digital and non-digital), traditional drawings,

[11] Britannica, The Editors of Encyclopaedia. "raster graphics". Encyclopedia Britannica, Invalid Date, https://www.britannica.com/technology/raster-graphics. Accessed 27 December 2021.
[12] Britannica, The Editors of Encyclopaedia. "vector graphics". Encyclopedia Britannica, Invalid Date, https://www.britannica.com/technology/vector-graphics. Accessed 27 December 2021.
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[15] https://www.iana.org/assignments/media-types/media-types.xhtml
[16] https://en.wikipedia.org/wiki/List_of_file_formats

Vectorial

***vector graphics**, mathematically based computer image format.*

Vector graphics, composed of lines defined by mathematical formulas, were first used in computer displays in the 1960s and '70s. The displays were essentially modified oscilloscopes, and vector graphics were used because the memory that would be needed for displaying raster graphics, or bit-mapped graphics, was too expensive. Vector graphics were also used in early arcade games such as Asteroids. By the 1980s, raster graphics, which use dots called pixels to create an image, had all but replaced vector graphic displays.

- All data deriving from three-dimensional surveys with surveying instruments such as total stations and 3D laserscan.

Text

Text documents come in two flavors - rich text and plain text. Plain text, as you might have guessed, is rather plain. It supports standard ASCII characters, including numbers, symbols, and spaces, but does not support any type of text formatting. Therefore, you cannot apply bold, italic, or underlined styles, and you cannot use different fonts or font sizes in a plain text document.

- Non-graphical data, technical reports.

Multimedia

As the name implies, multimedia is the integration of multiple forms of media. This includes text, graphics, audio, video, etc. For example, a presentation involving audio and video clips would be considered a "multimedia presentation." Educational software that involves animations, sound, and text is called "multimedia software." CDs and DVDs are often considered to be "multimedia formats" since they can store a lot of data and most forms of multimedia require a lot of disk space.

- Video, audio formats, web sites

Essentially, we can distinguish between:

- Proprietary formats

These are formats licensed by software houses. Generally, you do not have the complete code available and this places limits in their use. They have strong limitations due to the obsolescence of the format and their intelligibility.

- Open format

Open formats guarantee a readability and durability over time that is unparalleled. They are not licensed directly from software companies, but from academic realities or non-profit associations. Their being Open, allows you to improve and expand their potential through programming tools.

<u>For what has been said, in order to make HBIM information available to several subjects and at different times, it is recommended, where possible, to use Open file formats.</u>

AgID: the guidelines for electronic documents[17]

In Italy there are agid guidelines that from 2020 regulate the document management of data.

It is interesting to mention what is present in Annex 2 dedicated to "File Formats"

“Below is a summary and non-exhaustive cataloguing of the most popular file formats and packages, according to their specific use ("typology"). Alongside each type of format, the relevant formats covered by this Annex are indicated; if the file extension associated with the format is different – unless uppercase – from the possible acronym of the name of the format itself, it will be indicated next to the name in parentheses (e.g., the PDF format will not have an extension indicated in parentheses as its default extension is already .pdf).

- Paginated documents — PDF, Microsoft® OOXML (.docx) e Word (.doc), OpenDocument Text (.odt), Rich-Text Format (.rtf), EPUB, PostScript™ (.ps), Adobe® InDesign® Markup Language (.idml);
- Hypertexts — XML, dialetti e schemi XML (.xsd, .xsl), HTML (.html, .htm), fogli di stile per XML/HTML (.xsl, .xslt, .css), Markdown (.md);
- Structured data — SQL, CSV, Microsoft® OOXML (.accdb) e Access (.mdb), OpenDocument Database (.odb), JSON, Linked OpenData (.json-ld), JWT4;
- Electronic mail — .eml, .mbox;
- Spreadsheets — Microsoft® OOXML (.xlsx) e Excel (.xls), OpenDocument Spreadsheet (.ods);
- Multimedia presentations — Microsoft® OOXML (.pptx) e PowerPoint (.ppt), OpenDocument Presentation (.odp);
- Raster images — JPEG (.jpg, .jpeg), TIFF (.tif, .tiff), PNG, GIF, OpenEXR (.exr), JPEG2000 (.jp2k, .jp2c, .jp2), DICOM, Adobe® DNG, Adobe® Photoshop® (.psd), DPX, ARRIRAW (.ari);

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[17] https://www.altalex.com/documents/news/2020/09/23/agid-linee-guida-documenti-informatici

- Vector images and digital modeling — SVG, Adobe® Illustrator® (.ai), Encapsulated PostScript™ (.eps);
- Digital Models — StereoLithography (.stl); Autodesk® DWG™, DXF™, DWF™, FBX™.
- Typefaces — OpenType (.otf), TrueType (.ttf), Web Open Font (.woff, .woff2);
- Sound — Waveform RIFF / Broadcast Wave (.wav, .bwf), MP3, audio RAW (.pcm, .raw, .snd), AIFF (.aiff, .aifc, .aif), FLAC, MusicXML™ (.music.xml), MIDI (.mid); molteplici codec audio;
- Video — formati video delle famiglie MPEG2 e MPEG4; molteplici codec video;
- Subtitles — TTML/IMSC/EBU-TT (.ttml, .dfxp, .xml), EBU STL;
- Multimedia containers — MP4, MXF, MPEG2 Transport/Program Stream (.vob, .ts, .ps), AVI RIFF (.avi), Matroska (.mkv), QuickTime (.mov, .qt), WebM;
- Multimedia packages — interoperable master package (IMF, IMP); digital cinema package (DCP); master for film distribution (DCDM); Digital Intermediate packages based on frame sequences (.exr/.dpx; .wav), ACES metadata file (.amf); parcel XDCAM;
- Compressed archives — TAR, ZIP, GZIP, 7-Zip (.7z), RAR, TAR compressed (.tgz, .t7z, ...) , ISO9660 (.iso), VMware® Disk (.vmdk), Apple Disk Image (.dmg);
- Administrative documents — electronic invoice, electronic health record, SAML SPID response, protocol signature
- Applications and source code — Microsoft executables® (.exe, .com), Java applets (.jar); Windows® (.msi), Android (.apk), macOS® (.pkg), iOS® (.ipa) application packages; static libraries (.a, .lib) and dynamic (.so, .dll, .dylib); interpretable scripts (.sh, .? sh, .bat, .cmd, .py, .perl, .js, .go, .r, ...); source code in various programming languages (.c, .cpp, .h, .java, .asm, ...).
- Cryptographic applications — electronic certificates (.cer, .crt, .pem), cryptographic keys (.pkix, .pem), electronic timestamps (.tsr, .tsd, .tst), cryptographic fingerprints (.sha1, .sha2, .md5, ...); for advanced electronic signatures and seals: XAdES (.xml), CAdES (.p7m, .p7s), PAdES (.pdf) cryptographic envelopes, ASiC containers (.zip); KDM (.kdm.xml)

6.3. How to manage and save data according to ISO 19650 standard[18]

To understand how to manage the geometric and non-geometric data typical of an HBIM project, we believe it is appropriate to refer to what is already applied in the field of Building Information Modeling (BIM) precisely because of the similar characteristics of managed data.

The amount and type of data in a Heritage intervention flow is manifold, as we have seen in the previous paragraphs.

This is due to the source of the data that is collected and the types of survey and survey that are used (see image below).

The amount of data in terms of Gbytes can depend on many factors, but usually, in the presence of surveys with laserscan3D and substantial photographic archives, it is easy to have to manage important amounts of data.

In a similar logic, even in the case of BIM design, you can find yourself managing similar amounts of information. For this reason, we believe that a management of the information collected in the Heritage field can be absolutely comparable to what is already happening in the BIM construction chain.

So let's see how the set of data is managed in a BIM order to be able to make a useful adaptation, if possible, to the HBIM theme.

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[18] ISO19650 - *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling*.

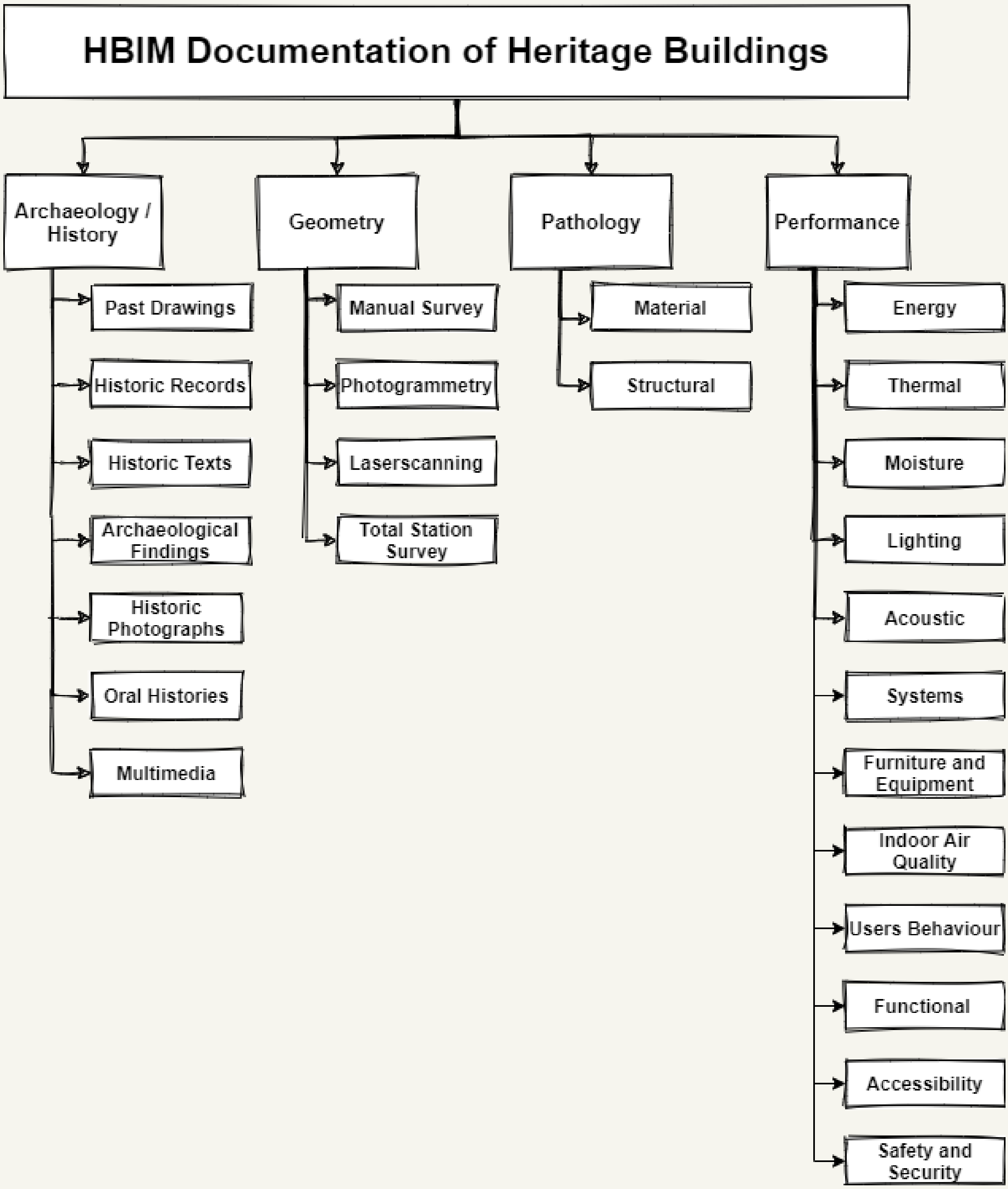

Figure 32 HBIM documentation data type

CDE in a BIM workflow

The management of data saved in a BIM stream finds its save environment in what is called the Common Data Environment (CDE).

When we talk about CDE we generally mean a specific platform accessible in the cloud that allows to guarantee a series of guarantees and technical requirements internationally standardized by ISO.

A CDE must be able to allow:

- to each container to have a unique ID, based on an agreed and documented convention consisting of a number of fields separated by a delimiter;
- each field to be assigned a value by an agreed and documented coding standard;
- each container has the following attributes assigned:
  - status (eligibility)
  - revision (and version)
  - classification (in accordance with the reference framework specified in ISO 12006-2);
- the ability of containers to move from one state to another;
- the recording of the user's name and the date on which container revisions pass from one state to another;
- controlled access at the container level.

as a result the typical functionality, performance and characteristics of a cde can be summarized as follows:

- accessibility, according to pre-established rules, by all the actors involved in the process;
- traceability and historical succession of revisions made to the data contained;
- support of a wide range of types and formats of data and their processing;
- high query flows and ease of access, storage and extrapolation of data (open data exchange protocols);
- conservation and updating over time;
- guarantee of confidentiality and security.

Goals and benefits using CDE

- Automation of information coordination between stakeholders;
- Transparency of information also in terms of authorship and temporal availability of information;
- Automated management of data revisions and updates;
- Reduced data redundancy;

- Reduce the risks associated with data duplication;
- Communication between interested parties through reference forms and interfaces (requests for info, requests, correspondence, etc.);

The primary objective of the CDE is to support the information management processes during the development stage of a contract.

At the end of a contract, the information containers required for asset management are transferred from the PIM Project Information Model to the AIM Asset Information Model.

ISO19650 standard: specific characteristics of CDE

The introduction of the ISO 19650 standard has brought a series of standardizations in the world of data interoperability and has updated the concept of CDE compared to what had been defined by the previous BS1192 of 2007.

The world of BIM, our reference in this approach to how to manage and save data, is a particularly important reference.

The success of the BIM workflow has led Heritage professionals to think of applying the principles present in the creation of an artifact also in the field of reuse and maintenance.

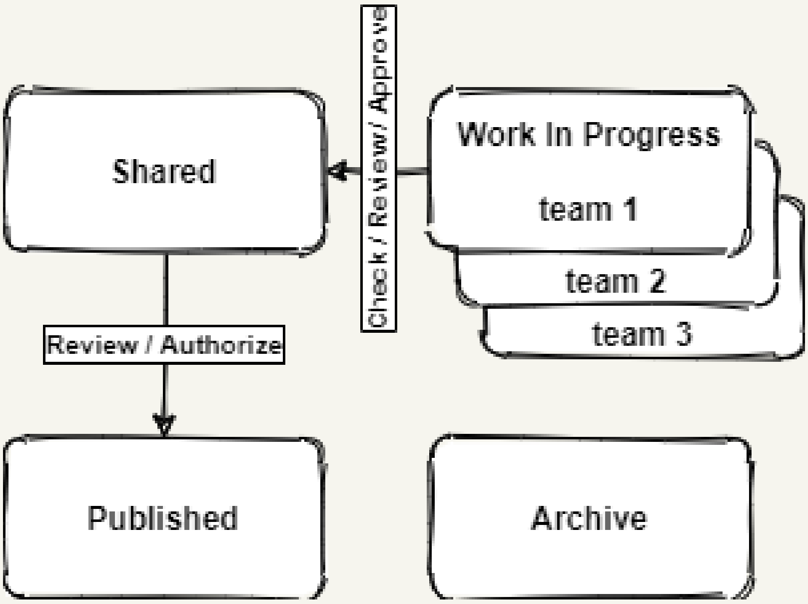

Figure 33 CDE data archivement

Even before the publication of ISO19650, in the world of BIM standardization there has been a whole series of considerations regarding the existing construction heritage, even considering assets of important historical value.

The inclusion of reuse and maintenance states in the Level Of Development (LOD) was a significant first step.[19]

In 2018, the publication of the first two parts of ISO19650 made it even more evident that Heritage heritage can also be included in the BIM workflow. In Europe it is applied through EN ISO 19650:2019 (parts 1 and 2) according to the ancillary standards of CEN TC442.

The information containers in a data sharing environment support four states/containers:

- Processing WIP status (L0)
- Shared share state (L1)
- Published status (L2)
- Archive status (L3), which in turn is divided into valid (L3V) and outdated (L3S).

L0 – WIP

The processing state is used by individual work tasks and can contain graphical and non-graphical information that is being refined. This environment may not be visible to the other groups that collaborate on the order.

HBIM- in the case of a Heritage intervention it can be assumed that this environment is dedicated to the processing of relevant data through specific tools such as Scalypso.

It can also be the environment where the group of BIM modelers begins to integrate the survey into the chosen architectural BIM platform (e.g. Allplan) before being able to share the result with the other professional figures involved in the project.

[19] We remind you that these LODs were introduced for the first time in the UNI11337:7 area and then shared and approved by CEN in the European context.

From the point of view of structural degradation, here you can set up the structural checks deemed necessary, before making them available to the members of the Heritage team in the shared state/container.

L0>L1 - Stato di Check / review / Approve

It is the obligatory transition between the data processing environment and the sharing environment, which therefore makes the data visible and accessible to all team members.

L1 – Sharing

In this context, the developed works are shared with the working group in order to better coordinate the work and highlight any shortcomings.

For Heritage, it can be the environment to be able to verify the completeness of the requested data.

L1>L2 fase di review / authorize

Models and data shared in the sharing environment can only be switched to the published environment if they meet the established requirements.

Documents that fail to pass the checks are moved to the WIP environment for appropriate additions and/or changes.

Useful step to verify the consistency of the data collected and the resulting BIM modeling.

It is also possible to start checks regarding the correct presence in the attributes of BIM objects of references and links to archives external to the CDE used. For this purpose it may be essential to be able to use software tools such as Solibri that allow such checks.

L2 – Published

It contains graphic and non-graphic information that has passed validation and sharing requirements.

At this level, the information can be used by project members and is valid until it is superseded by subsequent updates.

L3 – Archive

It is the environment that in the CDE preserves the data developed during the realization of the intervention, but which were then overcome by updates and changes.

6.4. Data Management and Storage: Considerations

Metadata / tag

The use of this additional data allows a better identification and management of the stored data. Their presence associated with what is stored can be easily identified and tracked by search engines.

It is interesting to consider that explanatory metadata and not exclusively numerical, can significantly increase the success rates in complex searches.

Among the main references we can mention:

- The Dublin Core Metadata[20] which sets the 15 basic parameters

    1. Title (Label: "Title")

    2. Author or Creator (Label: "Creator")

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[20] https://dublincore.org/

3. Subject and Keywords (Label: "Subject")
4. Description (Label: "Description")
5. Publisher (Label: "Publisher")
6. Other Contributor (Label: "Contributor")
7. Date (Label: "Date")
8. Resource Type (Label: "Type")
9. Format (Label: "Format")
10. Resource Identifier (Label: "Identifier")
11. Source (Label: "Source")
12. Language (Label: "Language")
13. Relation (Label: "Relation")
14. Coverage (Label: "Coverage")
15. Rights Management (Label: "Rights")

- The Pandora Australian Web Archive[21]

  Descriptive metadata for each object are stored in the NLA's library management system. Items in PANDORA are identified by means of a Persistent Uniform Resource Identifier (PURL). The PANDORA entities (metadata) are fully described in the PANDORA Logical Data Model document (NLA 1997).

- Research Libraries Group (RLG) Working Group on Preservation Issues of Metadata[22]

[21] http://pandora.nla.gov.au/about.html
[22] https://www.rlg.org/

6.5. Conclusions

What is seen in this chapter leads to a number of final considerations.

The data present in an HBIM stream can be of important types and quantities.

We must therefore not underestimate the issue of data retention, precisely because it can be a critical issue for any information retrieval operations years after their use.

In order to have guidelines to be inspired by, we believe it is important to underline what are *best practices* to follow in order to have a correct management of data:

1. In the case of documentation in non-digital formats, it is important to provide for a digitization of the same.
2. Where possible or interesting, provide OCR functionality of character recognition, to allow greater indexing of files.
3. The choice of the digital format in which to store the data must be guided by principles that aim at the possibility of making the data available using Open file formats. For this purpose, please refer to ISO 19005-1:2005[23]
4. The presence of appropriate Metadata makes it easier to identify the contents of the files.
5. A properly calibrated classification allows search engines to better identify the required files earlier.
6. The data sharing environment (CDE) must ensure controlled user access, wide accessibility and security that is free of any technical problems or unwanted intrusions as defined by ISO19650.

[23] Document management — Electronic document file format for long-term preservation — Part 1: Use of PDF 1.4 (PDF/A-1)

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Instruments & tools

ARK

The ARK (Archival Resource Key) naming scheme is designed to facilitate the high-quality and persistent identification of information objects

http://www.cdlib.org/services/uc3/arkspec.pdf

CrossRef

Crossref makes research objects easy to find, cite, link, assess, and reuse. We’re a not-for-profit membership organization that exists to make scholarly communications better.

http://www.crossref.org

DataCite

Locate, identify, and cite research data with the leading global provider of DOIs for research data.

http://www.datacite.org

DOI

The DOI system provides a technical and social infrastructure for the registration and use of persistent interoperable identifiers, called DOIs, for use on digital networks.

http://www.doi.org/

Perma.CC

Perma.cc is a service that helps anyone who needs to cite to the web create links to their references that will never break. Perma.cc prevents link rot.

https://perma.cc/about

Standards

UNI ISO 15489-1 - Information and Documentation - Managing Archival Documents - General Principles of Record Management.

UNI ISO 15489-2 -Information and Documentation - Managing Archival Documents – Record Management Guidelines.

ISO/TS 23081-1 - Information and documentation - Records management processes – Metadata for records – Part 1 – Principles, Framework for the development of a metadata system for document management.

ISO/TS 23081-2 - Information and documentation - Records management processes – Metadata for records – Part 2 – Conceptual and implementation issues, Practical guide for implementation.

ISO 16175-1 - (ICA) Information and documentation -- Principles and functional requirements for records in electronic office environments -- Part 1: Overview and statement of principles.

ISO 16175-2 - (ICA) Information and documentation -- Principles and functional requirements for records in electronic office environments -- Part 2: Guidelines and functional requirements for digital records management systems.

ISO 16175-3 - (ICA) Information and documentation -- Principles and functional requirements for records in electronic office environments -- Part 3: Guidelines and functional requirements for records in business system.

ISO 15836 - Information and documentation - The Dublin Core metadata element set, Sistema di metadata del Dublin Core.

ISO 9001 – Sistemi di gestione per la qualità – Requirements.

ISO 30300:2011 Information and documentation - Management systems for records - Fundamentals and vocabulary;

ISO 30301:2011 Information and documentation - Management systems for records – Requirements.

ISO 30302:2015 Information and documentation - Management systems for records - Guidelines for implementation.

ISO/TR 23081-3 - Information and documentation — Managing metadata for records — Part 3: Self-assessment method

MoReq 2001 Model requirements for the management of electronic records.

MoReq 2 Specification 2008 Model requirements for the management of electronic records – which identifies the functional requirements of document management.

MoReq2010 Modular requirements for records systems.

Standards for digital preservation

UNI 11386 - Standard SInCRO - Support for Interoperability in the Conservation and Recovery of Digital Objects.

ISO 14721 - OAIS (Open Archival Information System), Open information system for archiving.

ISO 15836 - Information and documentation - The Dublin Core metadata element set.

ISO/TR 18492 - Long-term preservation of electronic document-based information.

ISO 20652 - Space data and information transfer systems - Producer-Archive interface -Methodology abstract standard.

ISO 20104 - Space data and information transfer systems — Producer-Archive Interface Specification (PAIS).

ISO/CD TR 26102 - Requirements for long-term preservation of electronic records.

SIARD Software Independent Archiving of Relational Databases 2.0

Ministère de la culture et de la communication, Service interministériel des Archives de France, Standard d'échange de donnéès pour l'archivage. Transfert – Communication – Élimination – Restitution - Modification, ver. 2.1, 2018

METS - Metadata Encoding and Transmission Standard

PREMIS – PREservation Metadata: Implementation Strategies.

EAD (3)/ISAD (G)

EAC (CPF)/ISAAR (CPF)/NIERA (CPF)

SCONS2/EAG/ISDIAH

Cyber Security Standards

ISO/IEC 27001 - Information technology - Security techniques - Information security management systems – Requirements, Requisiti di un ISMS (Information Security Management System);

ISO/IEC 27017 - Information technology -- Security techniques -- Code of practice for information security controls based on ISO/IEC 27002 for cloud services;

ISO/IEC 27018 - Information technology -- Security techniques -- Code of practice for protection of personally identifiable information (PII) in public clouds acting as PII processors;

ETSI TS 101 533-1 V1.2.1 - Technical Specification, Electronic Signatures and Infrastructures (ESI);

Information Preservation Systems Security; Part 1: Requirements for Implementation and Management, Requirements to build and manage secure and reliable systems for the electronic storage of information;

ETSI TR 101 533-2 V1.2.1 - Technical Report, Electronic Signatures and Infrastructures (ESI); Information Preservation Systems Security; Part 2: Guidelines for Assessors, Guidelines for evaluating safe and reliable systems for electronic information storage.

LIST OF FIGURES

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Instruction

of Historic Buildings Inventory

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