ADVANCED, MULTIDISCIPLINARY, INTEROPERABLE DIGITISATION OF CULTURAL HERITAGE AND USER-FRIENDLY USE OF THE RESULTS: CASE STUDY OF THE CATHEDRAL OF SANTA MARIA ASSUNTA IN CIVIDALE DEL FRIULI (UD)

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ABSTRACT:

The Superintendency of Archaeology, Fine Arts and Landscape of Friuli Venezia Giulia has recently launched various studies and projects for the reduction of seismic vulnerability and the restoration of the region’s historical architectural heritage which, according to the indications of the Ministry of Culture, must be implemented in an exemplary manner both from a methodological and executive point of view. For the Cathedral of Santa Maria Assunta in Cividale del Friuli (UD), innovative solutions were sought right from the preliminary study phases, as well as new methodologies and technologies also in line with the indications of the European Commission (work programme 2018-2020 - LC-EEB-02-2018: design and development of “kits” to support BIM Authoring for restoration and interventions on existing buildings). The use of relevant technologies such as laser scanners highlights the limitations of solid and/or parametric solid modelling (BIM) processes when applied to the built environment. These limitations arise mainly because the reality of the built environment does not correspond to an ideal geometric model, but has variations and irregularities that are difficult to reproduce through traditional modelling techniques.
Within this context, it was essential to adopt innovative 3D modelling techniques, in order to meet the required accuracy of ≤5 mm and to catalogue - accurately and in advance - the architectural, structural and decorative elements present so as to obtain an effective and efficient 3D model. The aim of this work is therefore to present a successful experimentation that can open up new perspectives in the field of threedimensional reproduction of architectural heritage. In particular, the combination of the use of advanced technologies with preventive cataloguing and innovative techniques of participatory 3D modelling (crowdsourcing), in order to obtain advanced 3D models that are highly accurate and informative, as also indicated by the aforementioned European Commission directives.

1. INTRODUCTION

The development of digital technologies and the enhancement of internet connections have brought many innovations in the field of 3D digitisation of architectural heritage. However, there are still some challenges to face.
In particular, as regards the geometric aspect, it is necessary to devise new modelling techniques that allow for the faithful reproduction of the existing architectural heritage.

For architectural taxonomy as well, it would be desirable to develop innovative, easy-to-use, portable tools that are capable of expanding predictive investigations on site and involving multidisciplinary experts with different levels of expertise, without necessarily having to resort to 3D models.
Therefore, the 3D digitisation of architectural heritage arouses great international interest. Many studies have been conducted in this area, including the recent VIGIE 2020/654 study by the European Commission (April 2022) on the quality in 3D digitisation of tangible cultural heritage.
Nonetheless, despite the number of existing studies, it seems that precise guidelines have not yet been defined regarding the survey instruments and modelling techniques that allow for achieving millimetre and sub-millimetre accuracy in large historical architecture.
Solid or parametric solid modelling techniques are used in the context of BIM (Building Information Modelling) or HBIM (Historic Building Information Modelling) to create detailed 3D models of architectural structures.

Figure 1. Cathedral of Santa Maria Assunta in Cividale del Friuli (UD)

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However, these models are limited by their nature based on regular geometric shapes, which do not take into account the deformations and irregularities present in the masonry and horizontal structures of historical architecture.
This can lead to models defined as “simplified”, that do not allow for an accurate investigation to understand the historical mechanisms in place on ancient structures.
In general terms, the structural diagnosis of a historic building is based on a crack mapping analysis, i.e. on the critical observation of all the cracks present in the structure; these represent the evident manifestation of discretisation of the original masonry continium due to external actions (earthquake, subsidence of the foundations, phases of transformation, etc.). Very often, the cracks undergo concealment processes (grouting, plastering, etc.), which take away the valuable tools for the structural analysis of the existing building.
However, these forms of “repair” cannot cancel the deformation states linked to cracking; the reading of deformation patterns, as long as they are analysed with the necessary level of metric accuracy, makes it possible to compensate and supplement the unavailability of crack mapping.
The reading of deformations within masonry parts not affected by observable cracking phenomena is an important indicator of poor masonry quality, which is useful information both for structural modelling and for choosing any structural intervention.
For this reason, the European Commission’s LC-EEB-02-2018 project focuses on the creation of “kits” to support BIM Authoring in restoration interventions and in modelling of existing buildings, including highly accurate 3D models, which allow for an accurate and detailed analysis of the deformations of structures, in order to ensure an effective design.
Therefore, it becomes essential to certify the accuracy of the 3D model of the historic building, so that the designer can take design decisions with certainty, on the basis of a precise and reliable model.
It is equally well known that modelling techniques are only one factor influencing the accuracy of a 3D model. Other factors, such as the quality of the input data, the resolution of the polygon meshes and the 3D modeller’s experience can significantly affect the quality of the final model.
To achieve a millimetre or sub-millimetre rendering of the built structure, it is then necessary to use highly precise measuring instruments (at least three or four times greater than the required tolerance) and tested operating methods.
In the processes of design, management and monitoring of historic buildings, a 3D model becomes more effective and efficient if it considers not only geometric accuracy, but also the semantic aspect, i.e. the correct nomenclature and classification of the architectural elements.
However, neither AI nor 3D operators can replace the culture, experience and sensitivity of experts, which is necessary to both understand the history and function of each element of the ancient building and create an accurate and complete thematic model.
For this reason, it would be advisable for the nomenclature and classification phase to take place before the 3D modelling, thus avoiding the creation of models that are difficult to use.
This preparatory activity is even more important if we consider that, in order to reduce the time required to create the model, it is possible to employ more remote operators, who need shared terminology.
In this essay we wish to illustrate the solutions adopted in the survey of the Cathedral of Santa Maria Assunta in Cividale del Friuli, commissioned by the Superintendency of Archaeology, Fine Arts and Landscape of Friuli Venezia Giulia.
The activity is part of the vast funding programme allocated by the Ministry of Culture for the reduction of seismic vulnerability of the historical architectural heritage which, according to national guidelines, must be developed in an exemplary manner both from a methodological and executive point of view.

The presentation will illustrate the following points:

2. Topographic survey and 3D laser scans;
3. Nomenclature and taxonomic classification;
4. 3D modelling - LIM (Lidar Information Model);
5. Importing the LIM on BIM Authoring;
6. Conclusions ù

2. TOPOGRAPHIC SURVEY AND 3D LASER SCANS

The quality of the survey, as input data, becomes essential to ensure satisfaction of the accuracy required of the 3D model, both at a general and local level. The general accuracy is understood as the correspondence of the 3D model to the actual building in its complexity, while the local accuracy is understood as the correspondence to each single element making up the building.
The topographic activities (Fig. 2) performed include: cartographic framing with GNSS instrumentation, with a deviation ≤ 10 mm; polygonation with mean linear deviations ≤ 1.5 mm for the closed and open polygons bound at the endpoints; forward and reverse high-precision levelling which involved all the vertexes of the polygons and establishing new cornerstones, with a closing deviation ≤ 0.32 mm. The 3D scans were performed with TLS Terrestrial Laser Scanners based on “phase difference” technology. The mean measurement accuracies, considering the colours and materials of the objects, are equal to ≤ 0.6 mm over distances of less than 25 m and ≤ 1.57 mm at 50 m. 605 instances of TLS stationing were performed, from which approximately 15.68 billion points were detected, with a total disk space occupied equal to 855.72 gigabytes.

Figure 2. Topographic activities: closed polygon in blue; open polygon with bound endpoints in orange, vertexes of the polygons detected with precision levelling in yellow; free STT (Theodolite Total Station) stations in green; micro-prisms in red

The alignment of the TLS datasets on the local Cartesian reference system, chosen to facilitate the use of point clouds and the 3D LIM in BIM Authoring, was performed with three distinct methodologies in order to curtail errors. These techniques include:

- target alignment;
- automatic alignment, which provides for the recognition of common geometric characteristics;

- cloud-to-cloud alignment, which analyses the entire point cloud captured from each location and compares it to other point clouds to find the best overlap.

The combination of these alignment techniques allowed for obtaining deviations between 2 and 4 mm, guaranteeing an effective positioning of the TLS data in the chosen Cartesian reference system.
This helped to ensure the local accuracy of the acquired data and, thanks to the topographical work described above, also the general accuracy of the 3D LIM.
During the topographic survey operations, eight microprisms were positioned on the structural elements in order to facilitate and accelerate the connection of the free topographic stations, necessary to acquire the targets for the subsequent rototranslation activity of the TLS (Terrestrial Laser Scanner) datasets.
The use of microprisms positioned on the structural elements also offers the possibility to carry out punctual monitoring, quickly and effectively, to verify any movements of the structures over time within a tenth of a millimetre accuracy (STT Theodolite Total Station) or even a hundredth of a millimetre (Laser Trackers).
In these cases, the information on the movements in progress assumes considerable diagnostic-structural relevance as they allow for the timely identification of potentially dangerous evolving phenomena.

3. NOMENCLATURE AND TAXONOMIC CLASSIFICATION

These activities represent one of the innovative aspects of the architectural survey process. For the survey of the Cathedral of Santa Maria Assunta (Fig. 3) the nomenclature and taxonomic classification of the elements were focused exclusively to support the 3D modelling activities.

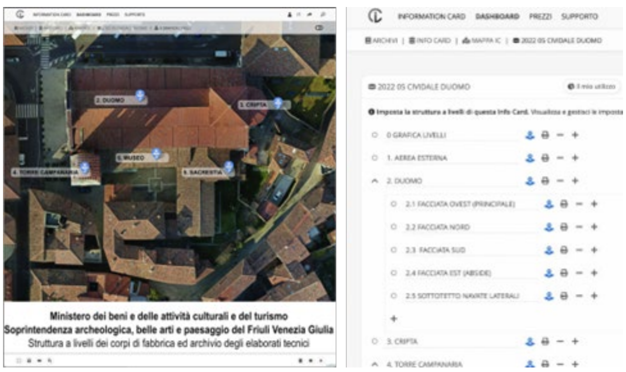


Figure 3. Classification of the body of buildings (infographic on the left) and hierarchical structure at levels on the right

The creation of an information archive (Fig. 4), although simplified in the coding and description of the architectural, structural, technological and urban furnishings elements (the latter for the external areas), was fundamental to prevent various 3D operators from using nomenclatures and subjective classifications that would have complicated the management and consultation of the 3D model.
This action was particularly important for the LIM (Lidar Information Model) modelling, as will be explained in the appropriate section.
Nothing prevents performing these taxonomic cataloguing activities even before the survey activities.
It would be even better if information archives already in use by national and international sector experts were to be used.

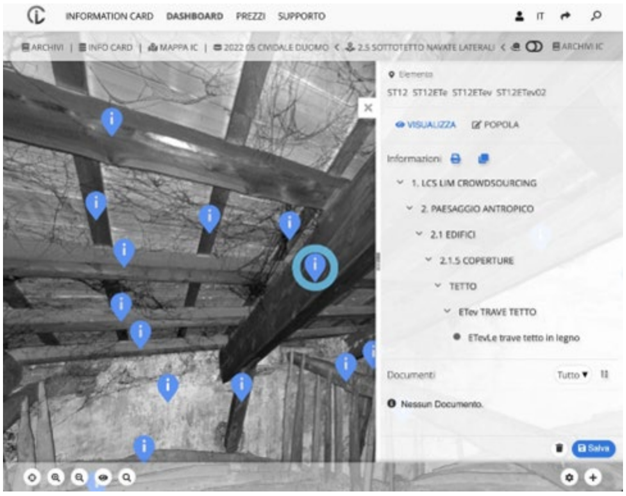


Figure 4. Identification of the elements, at the top right, the name of the element and the string of codes of the sets and subsets

This choice is also advisable as it would be of significant help in all cultural heritage digitisation processes, for example to:

- direct and facilitate the work of surveyors;
- avoid inventing subjective codes and classifications in the 3D modelling phase;
- learn about the state of the building(s) in advance;
- have the possibility of developing comparative analyses between the buildings and direct the priorities of the interventions;
- facilitate the planning, management and monitoring phases of the properties;
- promote and facilitate the exchange of information between clients and designers;
- strengthen the scientific value of the architectural survey and optimize the processes of fruition and dissemination of cultural heritage.

In the nomenclature and taxonomic classification activity of the elements, which is necessary for the efficient drafting of the LIM (Fig. 5), the online application, IC InformationCard (www.informationcard.eu) was used.

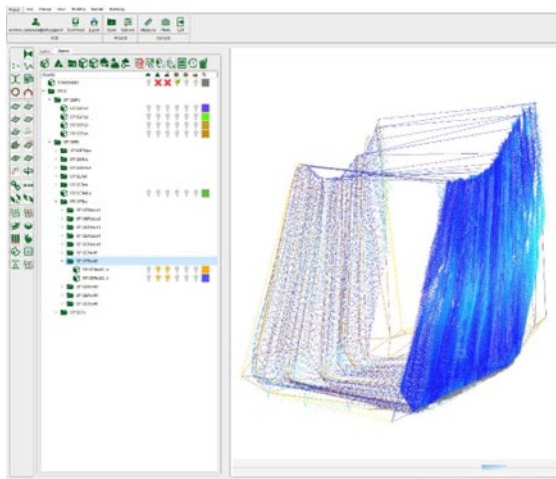


Figure 5. LIM of the beam object “ST12Tev02” (the accuracy certification cloud is in blue), shown in Fig. 4

This was specifically developed by Virtualgeo s.r.l. to allow for the collaboration of numerous 3D operators remotely in the creation of the model, even of a single building. The online

application uses multidisciplinary archives to link the necessary information to Points of Interest (POI) on 360degree views, even in very high definition (gigapixel), thanks to the implementation of tiling algorithms.
A dedicated archive was created for the nomenclature of the elements present in the buildings covered by the surveys, which, although simplified, contains a code and a brief description for each object present.
For classification into sets and subsets, a coding that precedes the code of the objects-elements has been used. 3D operators will use this coding to generate folders and subfolders containing the various objects and elements.
In brief, the name assigned to the POI is a string of codes, where the former represent the sets and subsets, and the latter represents the identification of the objects.
The activities carried out for the Cathedral of Santa Maria Assunta, in support of the 3D modelling activities and consisting of 3,994 identified elements, are as follows:

- photographic survey and drafting of equirectangular images (360-degree photos);
- creation of an information archive and codification of environmental, structural, architectural and decorative elements;
- creation of a level and sub-level structure of the various body of buildings present;
- population of equirectangular images (360-degree photos) on the infographics of the various levels; • cataloguing of elements: positioning of points of interest (POI) and linking to the information archive.

The use of 360-degree views for cataloguing offers numerous advantages, including the possibility for 3D operators to remotely resolve any interpretative doubts in the event that the TLS datasets do not allow for a complete understanding of the element being modelled.
Furthermore, the technology is user-friendly because it is already known to the public thanks to digital visits (commonly defined as "virtual") of monuments. This facilitates the interfacing with experts of any discipline and with clients, and allows designers to carry out remote inspections and enrich the points of interest already present with further information or add new ones to fulfil specific needs.
In the case of the survey of the Cathedral of Santa Maria Assunta in Cividale, the IC InformationCard application was also used as cloud storage to facilitate the sharing of the drawings produced between the design team and the client.

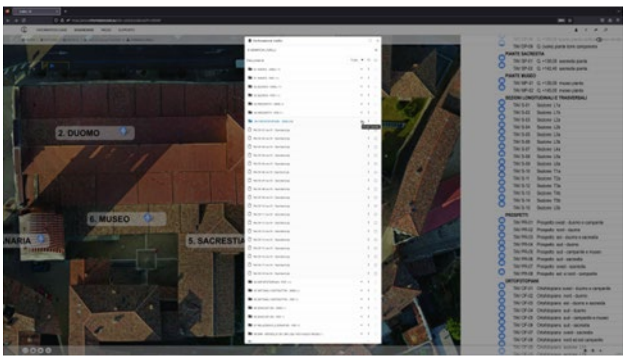


Figure 6. Cloud storage of all 2D and 3D drawings produced (in the centre) and related list with high-resolution preview up to Gigapixel for orthophotos

In addition, multimedia content has been included such as 3D models, certification infographics of the LIM, images of the architectural drawings, high-definition orthophotos and illustrative videos (Fig. 6).

This allows any user to view the entire work without necessarily having to use specific software.

4. 3D MODELLING - LIM (LIDAR INFORMATION MODEL)

Before explaining the LIM (Lidar Information Model) (Fig. 7) and its modelling techniques, it is important to briefly reference the types of 3D models, especially those used in architecture. 3D modelling was created as a design support in the industrial sector in the late 60s and expanded in the 80s with the spread of personal computers, further extending to many other sectors, including architecture, infrastructure and environment. The 3D modelling techniques are different (solid, surface, volumetric) and depend both on the nature of the object to be represented and on the objectives that the 3D model must meet.
3D representation essentially has two objectives: the first concerns the design of new objects or the reconstruction of what no longer exists, creating a virtual reality; the second objective is the three-dimensional reproduction of what already exists, creating a digital reality.

Figure 7. LIM detail of the interior (as "wireframe") of the Cathedral of Santa Maria Assunta

Excluding the volumetric 3D modelling techniques used, for example, in the simulation of fluids, those with solids are effective for the creation of virtual realities, while those with surfacing are indispensable in reverse engineering activities, i.e. in reverse engineering for the faithful reproduction of what already exists by creating a digital reality.
The field of architecture presents both aspects. Both that of new design (virtual reality) and that of the recovery and restoration of historical heritage (digital reality). It is therefore important to recognize that, although BIM or HBIM is an excellent solution for the management and preservation of cultural heritage, solid and parametric solid 3D modelling techniques - commonly used in the architecture sector - may have some limitations in the faithful reproduction of reality.
Within this context, it may be useful to also consider other modelling techniques, such as surfacing, to ensure a more accurate representation.
This is not to downplay the importance of BIM or HBIM, but rather to emphasize the importance of using the right methodology according to the specific needs of the project. However, surface modelling techniques can also have pitfalls when using TLS data as input. These pitfalls include the presence of anomalous points, data redundancy, the presence of "tail-of-a-comet," missing parts and, above all, the high number of points present.
All these aspects have been highlighted over the years thanks to the experience of many 3D modelling experts, and represent challenges that a fully automated approach cannot solve completely. In other words, there is no universal, perfect solution to handle these situations.

Creating three-dimensional models of the historical architectural heritage and of the built environment in general, with millimetre and sub-millimetre level accuracy that also include the classification of objects, still represents a great challenge.
The Lidar Information Model (LIM) can represent one of the solutions to this challenge and could be implemented in BIM processes for the representation of historical buildings, infrastructures and, in general, also “as-built” for new buildings. As described above, the main objective of the LIM, which constitutes the foundation of Virtualgeo’s research activities (the technologies produced for the realization of the LIM are not present on the market as they are subject to continuous experimentation, therefore for internal use only and/or for educational purposes starting from high school), is to allow the exact reproduction of architectural reality, in order to respond to not yet satisfied needs such as:

- quickly perform exact metrological investigations on buildings affected by natural disasters or any other manmade event. Investigations that 3D BIM or HBIM models cannot allow because they are simplified;
- show the actual state of deformations and settlements of the architectural elements and structures (out of plumb, bulging, depressions, etc.) to support the design (Fig. 8);
- avoid the use of massive, complex TLS datasets within the BIM authoring processes and allow for the creation of a solid and parametric solid model, as well as exact architectural representations, in a simpler and faster manner.

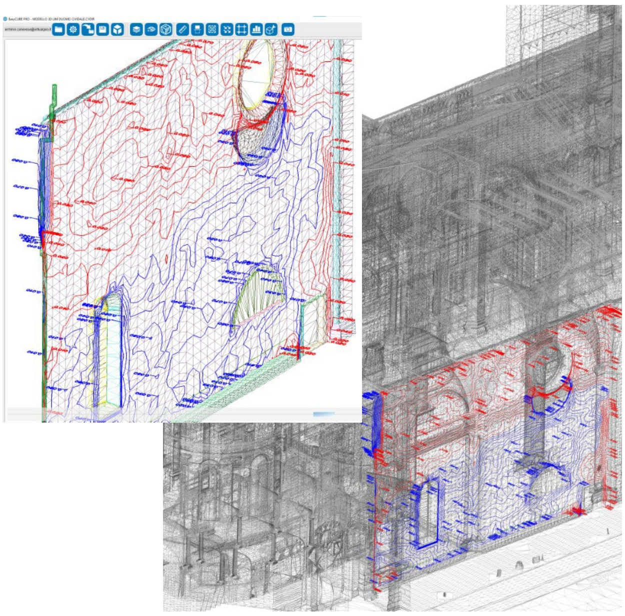


Figure 8. Metrological investigation (bulging and out of plumb) on a single wall element of the LIM. The colours with the arrows, together with the numerical value, indicate the direction of the deformation (blue towards the inside and red towards the outside)

The phases that led to the creation of the 3D model of the Cathedral of Santa Maria Assunta, for which an accuracy of ≤ 5 mm was required, are as follows:

- segmentation of the entire TLS dataset into 117 parts;
- addition of the different parts (point clouds) in the IC InformationCard online application;
- 3D surface modelling with semi-automatic techniques by remote 3D operators (Fig. 9), including the certification of accuracy for each individual element and any of its components (Fig. 10 and 11).
- receipt of certified LIMs of the 117 parts;
- assembly and joining of all 117 parts.

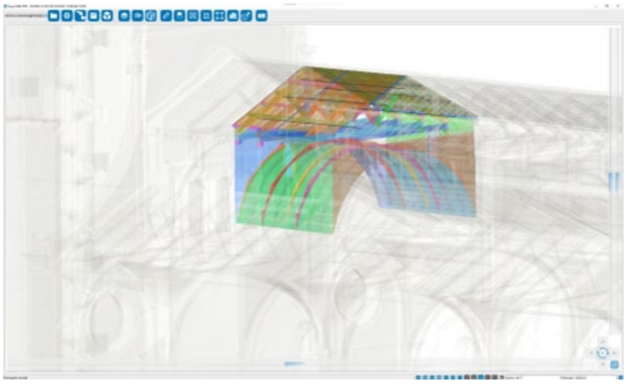


Figure 9. LIM of one of the 117 partitions, created remotely and classified on the basis of the indications present in the IC InformationCard

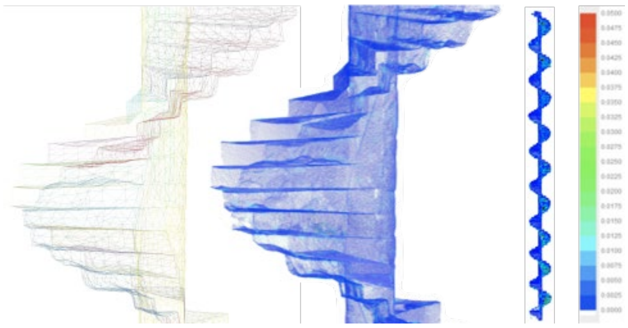
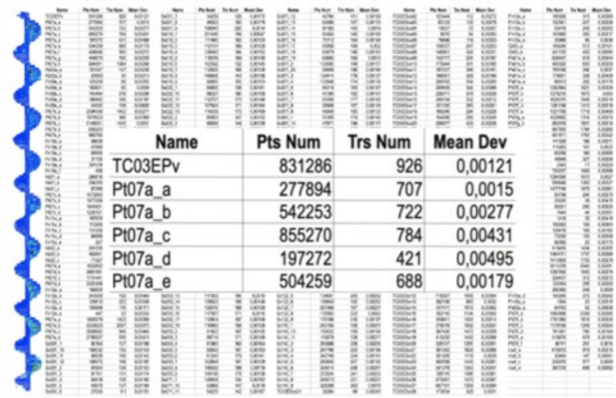


Figure 10. Extract from the visual certification report of the accuracy of one of the 117 partitions of the LIM. False colour images with the colour bar on the right with the numerical values of the deviations (from blue=0.00 m to red=0.05 m)



Name	Pts Num	Trs Num	Mean Dev
TC03EPv	831286	926	0,00121
Pt07a_a	277894	707	0,0015
Pt07a_b	542253	722	0,00277
Pt07a_c	855270	784	0,00431
Pt07a_d	197272	421	0,00495
Pt07a_e	504259	688	0,00179

Figure 11. Extract from the numerical certification report of the accuracy of one of the 117 partitions of the LIM, where:
Name: code of the modelled element
Pts Num: number of points in the TLS dataset
Trs Num: number of triangles in the LIM mesh Mean Dev: mean deviation between the triangles of the LIM mesh and the TLS dataset points

From the various phases of the process of creating the LIM of the Cathedral of Santa Maria Assunta, it can be seen that the main innovation does not lie as much in the mathematical algorithms, extensively and successfully analysed for years, but rather in the Cartesian process which has made it possible to divide the larger problem into smaller parts, assigning them to

different operators and, subsequently, assembling the results obtained.
This allowed for creating a 3D model with a ≤ 5 mm certified accuracy starting from a medium-large dataset, containing 15.68 billion points and occupying 855.72 gigabytes. The model was classified into architectural elements and built quickly, with individual part models taking an average of 3 to 5 person/days to be completed, depending on the number of elements and the skills of the different 3D operators.
The LIM (Lidar Information Model) of the entire architectural complex concerning the assignment consists of 3,574,969 polygons and 8,116 layers (objects) and occupies approximately 154.8 MB (DWG) and 127 MB (CVDIR proprietary format) of disk space, representing an approximately 5,556-fold reduction from the size of the original point cloud dataset.
Except in very particular cases in which the use of 3D TIN is necessary, the modelling techniques used in the rendering of the LIM envisage the drafting of polygonal meshes with 2.5D algorithms. This methodology involves dividing the object into different elements, which explains why the number of layers of the LIM increased to 8,116, instead of remaining 3,994, as many as the catalogued objects. The high number of layers present in the 3D model could be considered an obstacle in model management, however, this drawback can be easily overcome. On the other hand, the presence of a large number of layers offers a considerable advantage to designers, because the latter can carry out geometric investigations on each single element of the object in real time, such as, for example, surface calculations and metrological measurements. During the 3D modelling, the tolerance of the required accuracy was verified for each of the 8116 polygonal meshes. This verification is performed by calculating the orthogonal distance between the points of the TLS dataset and the surface of the polygon mesh to which each single point belongs. Subsequently, each point was given a colour based on the distance value and a false colour image was created using a colour scale, showing the accuracy of the 3D element. The overall accuracy of the 3D model, which consists of the correspondence between the measurements taken on the model and the actual ones between two points located anywhere in the building, is determined by the sum of the local accuracy of each single surface of the model elements with the errors of the topographical work and of the roto-translation interventions of the relative position of the TLS datasets. In summary, the LIM allows for obtaining a three-dimensional reproduction with the following characteristics:

- it is informative thanks to the prior classification of the elements by the experts;
- it is certified because, during modelling, the various 3D operators verified that the polygonal mesh of each element and its components complied with the required tolerance in reference to the TLS dataset. Furthermore, the previously described problems relating to “tail-of-acomet” (i.e. a trail of points of tangency to variations such as edges, roundness, etc.) and “shadows” (i.e. lack of points) have been resolved.
- it has small dimensions, thanks to a system that allows the number of polygons to be reduced, sometimes achieving accuracy tolerances better than those required. This is possible because the polygons that make up the surface mesh are not decimated as in the case of the automatic calculation of the TIN Triangulated Irregular Network, but are added, starting from a simplified polygonal mesh, only where needed to reach the required accuracy tolerances.

5. IMPORTING THE LIM ON BIM AUTHORING

The 3D LIM and the related graphic drawings obtained from it were imported into Graphisoft Archicad 25, a BIM authoring tool, as required by the technical specifications (Fig. 12). The BIM platform is the main environment for further design drafting and, as such, it must incorporate and contain the LIM, the graphic drawings and the orthophotos (Fig. 13) developed in the survey phase, and allow for generating further documentation by extracting it from the model.

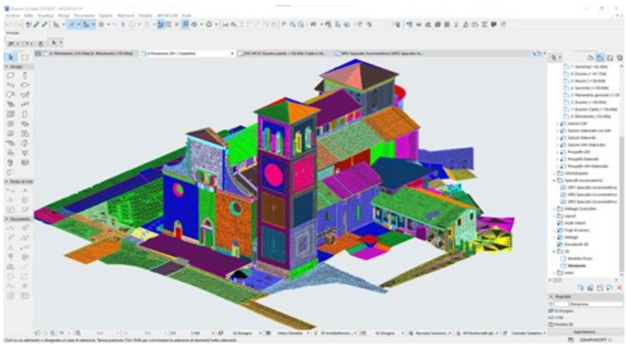


Figure 12. Importazione del modello LIM nel BIM authoring Archicad 25 (Graphisoft).

Figure 13. Visualizzazione dell’elaborato grafico fotogrammetrico, editabile, nel BIM authoring Archicad 25.

Thanks to its high accuracy, the LIM allows for obtaining exact, useful information such as plans, sections, elevations and axonometric and perspective cross-sections (Fig. 14) that can be queried by the user to analyse the geometry and properties of the artefact in question, eliminating the need to use TLS datasets, which may result in considerable management and interpretation difficulties due to their size (15.68 billion points and 855.72 GB).

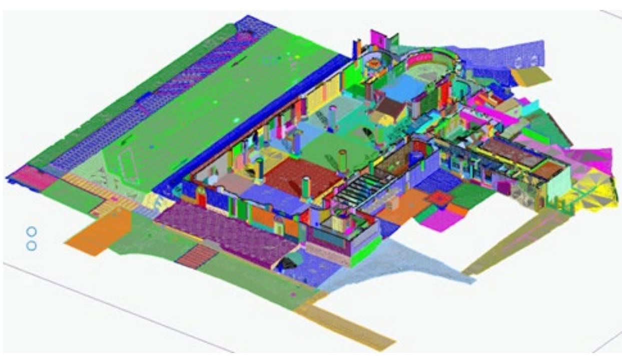


Figure 14. Drafting on the LIM in BIM authoring Archicad 25.

Nevertheless, since the surface model is not a native BIM element, generating new drawings requires the use of specific techniques and a longer computational time than those obtained from native BIM elements.
A further advantage of importing the LIM, is the direct comparison of each subsequent BIM modelling with the actual condition of the building, thanks to its high accuracy. This allows the modeller to explicitly evaluate whether the simplifications made to the modelling are fit for the purpose, and ensures an adequate level of accuracy and better quality control of the final drawing.
In this specific case, it was decided to import the LIM from the DWG format into a parametric object, not of the individual components, but of macro-elements, which when put together represent the body of the building.
The reason for the decision to group the components into macro-objects is that, although it would have been possible to implement a massive import solution of the single LIM elements, the complexity of managing 8,116 objects was not justified. In the LIM, in fact, the components are organised within a structure of folders and subfolders of layers that did not directly correspond with the version of the BIM authoring tool used (Archicad 25). In Archicad 26, the folders have been implemented in the combinations of layers and the replication of the LIM folder structure in BIM is being tested.
The decision to import the LIM into parametric objects was dictated by the authoring tool's peculiarity of using a real programming language, called GDL, in defining these objects. This made it possible to operate directly within the code to implement some functions not present at the time of the importing or to resolve some problems linked to the importing itself.
The adaptation of the importing technique to the specific BIM authoring tool is a somewhat debated topic because, if on the one hand it requires in-depth skills, on the other it opens up opportunities for exploiting the specific tools adopted which can improve the final result.
Each parametric object was assigned to a specific layer and the imported layers were then listed in the various combinations of layers, thus allowing the viewer to critically view the drawings and the imported LIM.

6. CONCLUSIONS

The research conducted on the documentation and the architectural survey of the Cathedral of Santa Maria Assunta, demonstrated the effectiveness of combining the use of taxonomic classification of architectural elements with modern 3D modelling techniques focused on reproducing the existing built environment with extreme, millimetre accuracy. The results obtained were highly satisfactory, as the LIM (Lidar Information Model), consisting of over 8,000 layers, made it possible to obtain a mean accuracy of ±2.5 mm on the surfaces of multiple elements.
This level of accuracy will allow for completing detailed projects, developing exact graphic drawings, and conducting metrology investigations on the current status of buildings as well as on future monitoring interventions.
The taxonomic cataloguing of over 3,900 elements proved to be an effective choice as it allowed for the correct naming and hierarchical ordering of the elements in the LIM, even by different 3D operators working remotely. Moreover, thanks to the online application, other experts can expand the information and manage the work in progress in a flexible manner and on any device.
This experiment therefore demonstrates the possibility of developing highly accurate semantic 3D models for existing buildings, on a millimetre and sub-millimetre scale, and their implementation in BIM Authoring in order to meet the needs of experts and owner-managers, without the need to use large point cloud datasets.
In the view of the European Commission directives mentioned within this study, we believe that it would be desirable to be able to expand technologies with new approaches to the BIM Authoring systems developed for the design, construction, and management of new works in order to meet, above all, the needs for the study and conservation of the architectural heritage. Furthermore, with reference to the IC InformationCard or similar solutions, it would be appropriate to encourage their development in order to ensure greater and better accessibility to new technologies for all those who, for whatever reason, do not need to equip themselves with tools such as BIM, for example, clients, scholars and humanities experts.
This would make it possible to carry out predictive analyses on a large scale, involving not only the professional world, but also the educational world, with the aim of promoting greater awareness of the value of cultural heritage and developing a critical sense that helps in choosing the most appropriate digital technologies to achieve set goals.

REFERENCES

Information Card, online software developed by Virtualgeo s.r.l. https://www.informationcard.eu/

EasyCubePro 9.2.0 software for visualize, query, classify and do metrology LIM developed by Virtualgeo s.r.l. https://www.geomaticscube.com/

EasyCubeLIM Master 5.94.00 and EasyCubeLIM Client 6.0.0, crowdsourcing platform to make validated LIM from survey data sets developed by Virtualgeo s.r.l. for internal R&D. https://www.geomaticscube.com/

Graphisoft Archicad 25 built 6000 BIM authoring developed by Graphisof SE. https://graphisoft.com/