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DIGITAL DOCUMENTATION AND FAST CENSUS FOR MONITORING THE UNIVERSITY'S BUILT HERITAGE

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ABSTRACT:

Digital 3D reconstruction in architecture is a powerful tool for monitoring construction sites, tracking project progress, and ensuring quality control. This method involves the use of digital survey technologies, such as drones, laser scanners, and 3D modelling software, to acquire precise and detailed data on the construction process. If we consider surveying to be a phase of documenting the existing, it is possible to talk about an architectural census as the process of collecting and analysing data on buildings and structures. This information is crucial for management and planning, as it can help identify issues related to building safety, accessibility, and sustainability. The research project aims to quickly obtain a database of documentation and historical, dimensional, morphological, and material knowledge of a university building in the historic centre of Pavia that is now disused, to develop an information system for quick census and monitoring.

1. INTRODUCTION

In the field of built Cultural Heritage (CH), highly reliable integrated digital surveying is a tool for the management and documentation of architecture projects (Parrinello et al, 2019). Digital surveying in this sense involves the use of technologies such as UAVs, mobile and stationary laser scanners, and 3D model management software (Beraldin et al, 2011; Picchio and De Marco, 2019). Considering the initial phase of surveying the existing CH as part of the process of documenting buildings and cultural heritage, it is possible to introduce the topic of architectural census as an additional process of data collection and analysis. The architectural census on literature typically includes information about the foundation, architectural typology, and condition of buildings in a city, as well as data on the use of regulations and codes, but all this information can be detailed according to the process of documentation (Semina et al, 2022; Miceli et al, 2020; Parrinello et al, 2023, Volzone et al, 2022). This information is used, with the help of digital technologies, to identify areas where interventions are needed and can be planned, such as where maintenance and rehabilitation work is required. In addition, an architectural census can be used to identify historic and culturally significant buildings and structures within a city, which can help inform decisions about preservation and adaptive reuse (Bruno et al, 2017; Morandotti, 2019). This help to maintain a city's architectural heritage while also supporting economic development. The research field of cultural heritage documentation for monitoring, about the action definition phase, is nowadays conducted with the support of Information and Communication Technologies (ICT), digital platforms, Information Systems (IS), databases and virtual environments as tools for facilitating decision-making processes (Al-Muqdadi and Ahmed, 2022; Barazzetti et al, 2022; Mishra, 2022).
This contribution deals with the use of digital technologies, in particular databases and datasets, in the field of built Cultural Heritage, by experimenting their use in a case study through integrated survey, documentation and management of the information collected for thematic groups, analysing aspects related to the state of conservation as support for restoration/maintenance interventions.

Figure 1. Top: drone photograph of the case study building at the University of Pavia. Bottom: image from point cloud in which the interior and underground six levels are visible.

The case study on which the methodology is being applied is a building in the historical centre of Pavia (Figure 1) currently in a state of disuse owned by EDiSU Pavia, *Ente per il Diritto allo Studio Universitario*, which is the subject of tenders for renovation and intervention works for the location of a subsidised catering service for students and employees of the University. The research project was conducted with the aim of obtaining the database for documentation and knowledge to support the client in activating the phases of intervention and new functional use.

2. DOCUMENTATION AND ANALYSIS

2.1 Project of digital survey and methodology

Three dimensional digital technologies are used extensively for the study and analysis of different aspects of CH that include 3D scanning, photogrammetric, colorimetric and textural surveys, 3D modelling, dissemination through Virtual Reality (VR) and Augmented Reality (AR) integrated with virtual fruition systems of the products obtained in 3D and 4D information platforms and systems (Savini et al, 2022; Trizio et al, 2021; Brusaporci et al, 2021; Sangiorgio et al, 2021; Kowalski et al, 2023). Actions and strategies for the protection of cultural heritage must be based on an in-depth knowledge of the heritage and the technologies used internationally, which together with coordinated management, documentation and knowledge of the assets contribute to reducing the risk of heritage loss. Measures currently indicated for risk prevention include monitoring and planned maintenance of the historical heritage; spatial planning and management; awareness campaigns and training of technical staff; cooperation of institutions and availability of economic resources; and legislative support (Chiabrando et al, 2018). Risk prevention is one of the phases of the strategic plan for the reduction of risks related to build heritage and works of art. The cultural heritage conservation sector attaches great importance to the use of principles to guide practitioners towards appropriate interventions (ICOMOS, 1998; UNESCO, 2010).

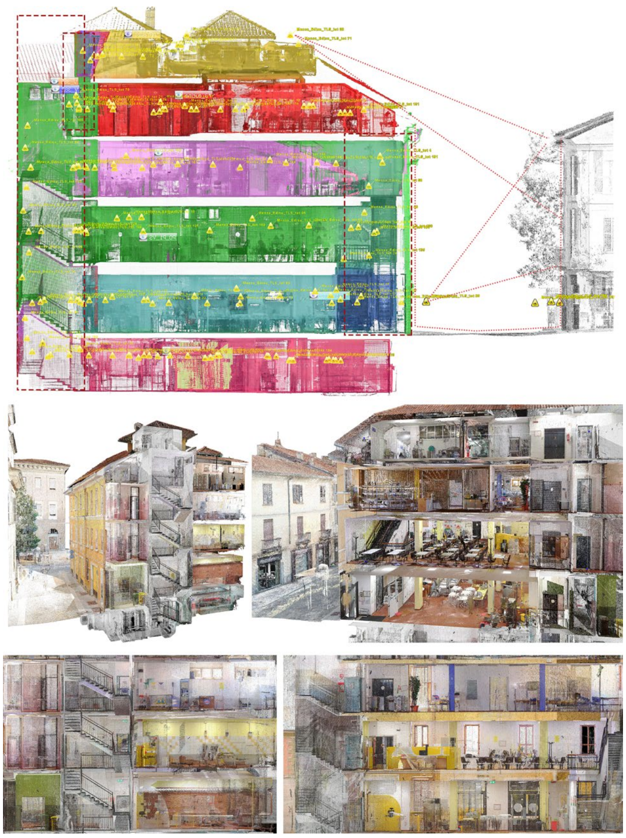

Figure 2. Images of the point cloud from TLS and UAV registered together. The original scans files from TLS in .fls format were processed by the FARO SCENE 3D Point Cloud Software, integrating data from the sensors (RGB camera, GPS, altimeter, compass). The scans were organised by registration clusters, developed in tree-like subsets, according to the polygonal path hierarchies (in planimetry) used during the survey and defined before starting the survey activites.

In this prevention scenario, the objectives of documentation mainly consist of preservation as a fundamental tool for resilience (Morandotti, 2017). The populating of databases is a widespread and essential support for the digitisation of the actions listed above. A database makes it possible to structure the information assets of an organisation or entity to make the data more easily consultable by external or internal users. Integrated into an information system, it allows data to be collected, processed, and stored, managing their distribution to support decision-making, coordination, and management activities (Morandotti et al, 2019). Storing data is not sufficient to extract information from input data, and databases are a combination of Create, Read, Update, and Delete an organised collection of data – the CRUD Paradigm. In computer programming CRUD represents the four operations of storage. The model, as cited the first time in Martin J. book "Managing the Data Base Environment" p.381, must be able to Create, Read, Update, and Delete resources. A model should have the ability to perform at most these four functions to be complete. (Martin, 1983). Databases for the documentation of the built heritage, understood in this paper to consist of highly reliable three-dimensional digital surveys and technological censuses of architecture, present characteristics of great utility for documentation and valorisation (Fassi, 2007; Teruggi et al. 2021), among which 3D digital representation, semantic partitioning of technological elements, high usability of digital models and populating the database with a highly usable interactive graphical interface are fundamental in this case.

Figure 3. Flight trajectories were planned for full and complete coverage of areas of interest and registration between different point cloud was obtained using target points (flight distance, data overlap, timing, and photographic shots).

2.2 3D database for monitoring the criticalities detected

The client's need was to document the current state of preservation of the building and monitor several critical issues found during a condition survey in February and May 2013. The survey had been carried out by a local professional studio that

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had reported with plans and photographic reports the alterations found and any signs of previous interventions that had not yet been recorded in the historical records of the Technical Office of the University. The goal of the actual research contract was to provide the client with a digital tool for the fast monitoring of conditions and high level of detail for the management and design of the new functionalisation of the building. The documentation project was conducted by a research team to ensure the integration of different digital survey instruments to obtain a complete and highly reliable metric database of the entire building complex.

Figure 4. Registration of the different three-dimensional databases according to the reference system of the TLS reliable laser scanner using GPS points.

The building has a predominantly square plan and faces with two fronts on the streets of Pavia's historic centre and another two fronts on private internal courtyards; it has a basement floor, 4 floors above ground and a terrace from which it is possible to access the roofs and is accessible through a technical room. The first digital survey was conducted in July 2021 by integrating Terrestrial Laser Scanner (TLS) instruments, unmanned aerial vehicles (UAVs) piloted by certified pilots from the laboratories involved, and photographic and photogrammetric acquisitions with Structure from Motion (SfM) techniques, (Figure 2-3) using compatible targets for both Laser Scanner and photogrammetry to have known reference points (Picchio et al, 2020). The UAVs used are ultralight to operate safely in a highly dense urban environment with high traffic of people and vehicles during the survey phase, as opposed to other cases outside urban areas where different UAVs can be used (Campana, 2017; Mazzacca et al, 2022; Parrinello and Picchio, 2023). The TLS survey was carried out using the Focus2 150 CAM2 FARO for both the external fronts and the internal rooms and was preferred over the Mobile MLS Laser Scanner instruments due to the quality of the data that had to be obtained (Dell'Amico and La Placa, 2020; Sammartano and Spanò, 2018). The survey activities collected 175 made with RGB colour data during 4 days of surveying and the point cloud obtained has an average density of more than 2,800,000 points per square metre. Average density per sqm: 2,860,977 points. Point cloud recording performed with proprietary SCENE software; Maximum registration error: 3.9 mm, average registration error: 2.3 mm; Minimum overlap between scans: 24.1%. In addition to the scans with 360° rotation, refinements were also made at strategic points for linking scans such as, for example, to optimally record the scans made on roofs and external roads reducing overlapping errors. The survey activity included a planning phase for the positioning of the scans to obtain a complete cloud that can be easily recorded in the data post-production phase. The acquisition of the fronts facing private courtyards and roofs was achieved by obtaining a point cloud from Structure from Motion technique using DJI Spark and Mavic Mini UAVs. Manual flight trajectories were planned according to the flight distance, the overlap of the individual photographs and the time required. In this way, flight missions were planned to consider mainly battery life (DJI Spark: 10 min; DJI Mavic Mini: 30 min) and the maximum RC reception distance (DJI Spark: 150 m; DJI Mavic Mini: 500 m). A total of 515 photographs were taken at a resolution of 4000x2250 mpx. SfM photogrammetric processing was conducted using GPS information to optimise the alignment of the acquired photographic data. The photographic acquisition campaign was conducted with digital cameras with the goal of obtaining an archive of descriptive images of the geometric and material consistency of the external surfaces and the interior spaces, functional for the survey of the state of conservation of materials and surfaces and construction and technological elements. In addition, the photographic acquisitions were conducted using the SfM technique by integrating data from the picture's shoots in the ground and UAV images to avoid deformations of the photogrammetric model due to foreshortening. The integration of the different point clouds into a single database (Figure 4) and with a single reference system was carried out on the Leica Cyclone software; the overall registration was conducted by identifying unique and homologous points, and the error found by the registration analysis calculated based on the alignment of the targets has a maximum of 0.03 m (maximum alignment error). The integrated database allows the data to be read at different levels, depending on the choice of display set: Colorimetric (UAV, TLS); Reflectance colours (TLS); Thematic maps based on preset values (UAV, TLS).

The GPS localization information present in the acquisition campaign data ensured a preliminary overlap between the TLS and UAV point clouds, both in height and in planimetry. To optimize the GPS data, the data alignment procedure between laser scanner and drone was done taking the GPS points and TLS point cloud as a reference, defining key targets registered on the UAV point cloud - the fixed targets positioned at the start of the survey. The average density of the integrated point cloud is 1 point/2 mm (Table 1).

Mean Absolute Error		
Disabled Constraints	0.000m	
Enabled Constraints	0.000m	
Mensa Edisu TLS - Mensa Edisu UAV		
Constraints - Iterations	62	
Overlap Point Count	71000	
Overlap Error Statistics	RMS: 0.0304587 m	AVG: 0.023574 m
	MIN: 2.7054-005 m	MAX: 0.0946299 m
Overlap Center	(-12.674. 1.335, 6.782) m	
Error after global registration:	4.60642e-029 sq M	
Translation	(-20.505. 22.022; -92.911) m	
Rotation	(0.0033. -0.0080. -1.0000)	-123.103 deg
Error	0.000 m	
Weight	10.000	
Error vector aligned	[0.030 m]	
ScanWorld Transformations		
Mensa Edisu TLS		
translation	(0.000, 0.000)	
rotation	(0.0000, 1.0000, 0.0000)	0.000 deg
Mensa Edisu UAV MavicMini		
rotation	(-0.0033, 0.0080, 1.0000)	123.103 deg

Table 1. Alignment values between TLS (worldscan) and UAV data reference.

3. ANALYSIS OF ALTERATION AND STRUCTURAL CRITICALITIES

Document the architecture is also about the functionality and structural integrity of the built environment. Census of structural and technological problems in architecture is crucial to identify and address issues that can compromise the safety and well-being. Structural problems can arise due to a variety of reasons such as poor construction practices, inadequate maintenance, or natural disasters. The consequences of these problems can range from minor issues like cracks in the walls to major structural failures such as collapses (Taborof, 2020; De Fino et al, 2019). To conduct a census of structural problems in architecture, it is necessary to carry out a thorough inspection of the building's structure. Depending on the severity of the issue, appropriate measures may involve repairs, reinforcement, or even partial or complete rebuilding of the affected areas. In addition to addressing existing problems, it is also important to take steps to prevent future issues. This may involve implementing regular maintenance and inspection programs, using high-quality construction materials and methods, and adhering to building codes and safety standards. The census of structural problems and the use of information system in architecture is crucial to ensure the safety and longevity of buildings (Galantucci and Fatiguso, 2019; Oreni et al, 2017).

The census of structural and material alterations and pathologies was conducted following two ways: by verifying what was surveyed during the 2013 activities to monitor the possible progress of the critical issues; by conducting a full mapping campaign of the building (externally and internally) to verify that there were no further problems. The survey was conducted using a database with a highly usable graphic interface that could be populated with data during the visual survey conducted in the field. The survey of alterations was carried out using mobile instrumentation (tablet) equipped with a high-resolution camera and data entry platform. The census cards (Figure 5) are organised in such a way that it is always evident: the location of the pathology/alteration detected; the definition of the alteration according to the UNI 11182/2006 standard (ex “NorMaL 1/88”) and the ICOMOS atlas “Illustrated glossary on stone deterioration patterns”; the element affected by the pathology and whether structural or non-structural; the material; the state of progression, if detectable, and the actions to be taken.

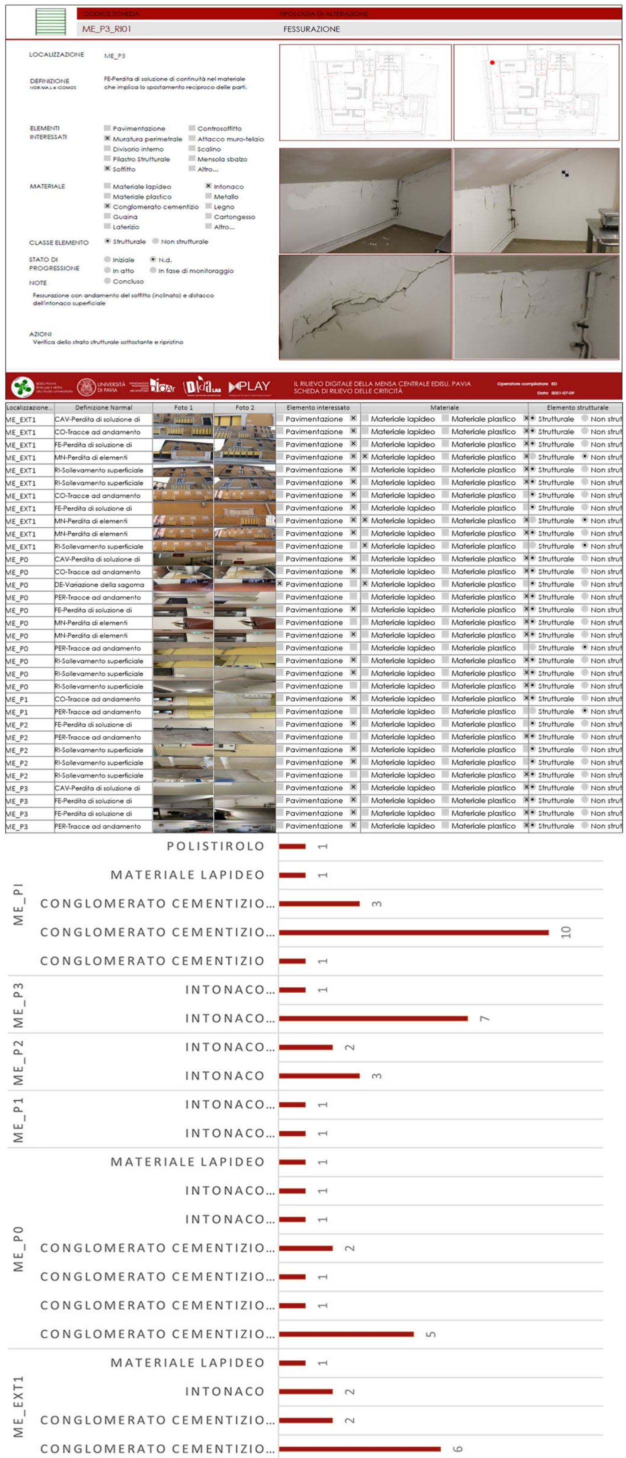

Figure 5. 54 census sheets were prepared describing the major alterations (swelling, detachments, presence of humidity, etc.) and structural criticalities (cracking, crazing) that were found during the survey. The census sheets are available in .PDF and .csv format. The data can be queried directly in the database or from the exported file.

Figure 6. Altered cracks in the basement technical room near the corner (red dot) of the building with subsidence related to the leakage of the sewage system.

Each card is provided with a unique code that can be traced back to the alteration and used as relational data in an information system, and the date of survey and name of the technician. For the project a Relational Database (RDB) was used; In RDBs data is organised in tables, each row of the table contains fields that store the information and multiple tables can be interconnected to create a richer and more informative tool creating relations. This census method is currently being tested in the laboratories involved in the project as a possible data collection methodology for structuring information systems integrated with three-dimensional GIS and BIM-HBIM modelling (Sanseverino et al, 2022; Di Benedetto, 2021). The census is compiled through records from the DB platform FileMaker and FileMaker Go platform, Claris International, which can be used from computers or portable devices (Munro, 2017). FileMaker integrates a database engine with a graphical user interface and security features, which allow users to modify the database by dragging new elements in layouts, screens, or forms. The choice of the DB platform was influenced by a number of factors, including: the presence of built-in database templates, layout themes and an intuitive graphical interface that allow new users to get started quickly; automatic creation of table, list and form views for all information and the possibility of displaying web pages associated with database records; easy Point&Click scripting language - a visual programming language - for to automate the desired processes without special programming skills and high usability; compatibility with iOS, Windows and Mac, both front end for querying a central server and central server and via database sharing between iPad, iPhone, Windows and Mac. The field phase was conducted using mobile devices, such as tablets and mobile phones, on which the FileMaker Go application is installed; the operations that can be performed are compiling, adding, searching, and sorting records, and executing scripts. The data entry operation directly in the field allows for optimisation of the survey time by combining the observation phase of pathologies with that of photographic documentation. Fundamental is the management of the card's unique code, which indicates the location of the alteration or degradation and the type, followed by a progressive number; this code corresponds to the degradation maps present in the graphic drawings. The data entry of images and photographs describing the presence of alteration take place directly in the building (on field) using a tablet and in post-production for points that are not accessible from the ground and for which photographic shots by SAPR or other instruments are necessary.

The main critical issues (Figure 6) found are related to the air/water ventilation and cooling systems that are not in use. The infiltrations found were caused by problems with the insulation of the roof and cracks in the pipes of the toilets and installations. On the other hand, from a structural point of view, significant cracks were found in the basement rooms at the south/west corner of the building; this portion of the building was particularly subject to foundation failure due to a leak in the city's sewer system located under the perimeter road. This has affected the building by creating a series of cracks that can be traced back to the same stresses and are all part of the same crack pattern. The cracks are evident in the two corner façades on the street, with an inclination of between 10 and 45 degrees and incident on the window corners and in the basement rooms with critical cracks that have affected the load-bearing structure. These cracks had already been monitored with crack gauges in 2013 and the inspections showed no deterioration in three out of four cracks. The fourth crack gauge, on the other hand, indicates an advancement of the lesion which, as it has not been monitored annually from 2013 to the present, is not reliable and could be altered due to misplacement.

Following this detection, the placement of an additional crackmeter was proposed to monitor the lesion and a plan of periodic inspections to assess whether the crack pattern is historicised or evolving. The crack was detected with TLS instrumentation and was oriented with respect to the entire building, so that a monitoring plan supported by the digital survey could proceed.

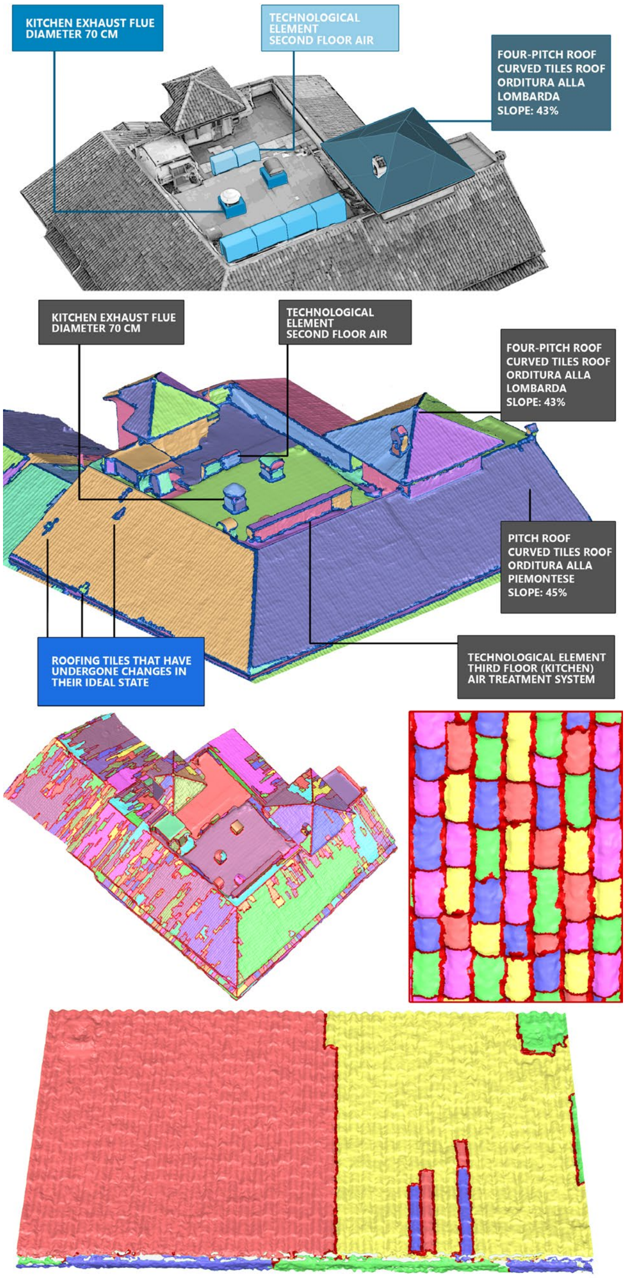

Figure 7. Top: Manual partitioning of the roof into technological elements. Middle: elements of the architecture identified through the analysis of the curvature of the mesh model obtained from the survey (tiles shifted from their correct position). As the overlap between adjacent tiles increases, the localised slope detected by the model becomes more evident. Bottom: Curvature analysis applied to the mesh model. The application of correction processes to the polygonal grid improves the curvature analysis map, increasing the recognition of technological geometries at different scales according to parameters; this phase of the research is under development in the Dada-LAB research lab of the University of Pavia. (De Marco and Doria, 2022).

4. ONGOING RESEARCH AND CONCLUSIONS

The interaction between digital information systems and diagnostics and scheduled using digital automated tools for inspections can be used as a method for understanding related data. By integrating, insert, and updating data in an information system, the aid is the development of semi-automated analyses to monitor the evolution of the built heritage. This technology aids the development of heritage digitisation and digital information archives, such as the development of built heritage management protocols. Starting from the partition and categorisation of data, it is possible to activate monitoring systems based on the comparison of temporally successive phases, particularly useful for CH in which is possible identify the constructive phases. The result of this research represents the first steps for a useful methodology for the design of built heritage management systems, aimed at different professional figures. In addition to what has been presented, a follow-up research phase is nowadays focusing on automatic geometry recognition and identification, recalling some processes already tested in the research laboratories involved (Figure 7), both related to surface recognition (De Marco and Doria, 2022) and object detection, a computer vision branch (Doria, 2022).
In particular, the process of geometry analysis is intended in this case to support the activity of management and maintenance at height, aiming to reduce the use of on-site workers in situations of documentation of the current state at height. The results of the research activity validate the use of information tools realized in a short time, thanks to the quick census and survey. The goal of documenting and making accessible an architectural asset that is currently subject to significant risks is of current interest. The possibility of comparing the results obtained during the diagnostic phases and the repeatability of the process on further assets serving and owned by the University of Pavia is part of a wider-ranging project to document and monitor the condition of architectural contexts (Picchio et al., 2020; Cecchini et al., 2020; De Marco and Doria, 2022; Morandotti et al., 2019b). Additional survey data collected during the scheduled periodic inspections are integrated into the information system to update the existing one and produce a digital medium for management.

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