Tradition in Innovation. Some Considerations on SLAM Technique Integration for Historic Buildings

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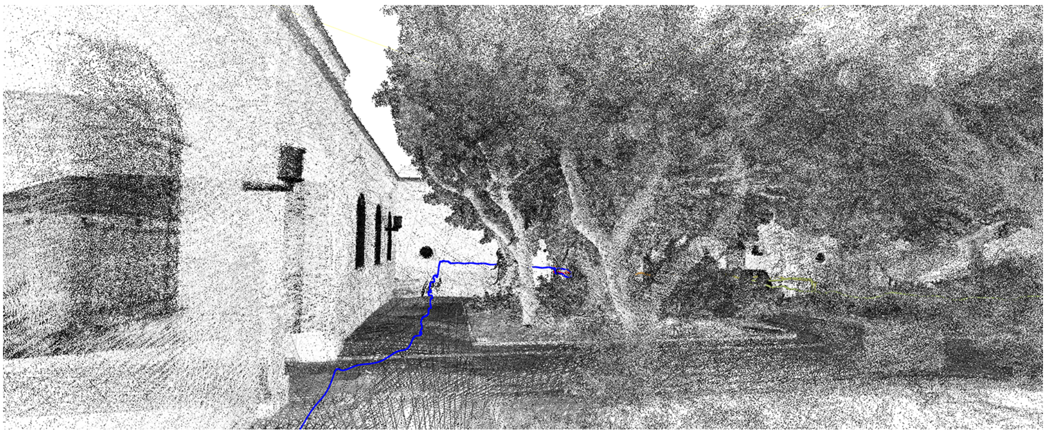
Abstract

Digital processes for modelling the historic built environment have changed research methods, expanding the domain of knowledge that surrounds cultural heritage, involving different expertise. Research activities make use of methods and tools, thinking of methods as permanent concepts in a process in which hardware and software tools, on the contrary, change as a function of continuous digital evolution. To preserve a conscious knowledge of the artefact, it is appropriate to review the new modes of massive accumulation of information about processes consolidated in time and history. In the field of digital surveying, some techniques and technologies are more suitable than others for this critical reinterpretation, allowing the integration of innovative activities through the support of traditional concepts. We are talking about laser surveying using SLAM (Simultaneous Localisation and Mapping) technology, which is particularly useful for surveying sites in difficult-to-reach locations. This technology presents a dynamic way of acquiring spatial information, centred on the prefiguration of capture paths capable of producing clouds of centimetric accuracy, which can be implemented through integration with other technologies. The integration process was tested on the monastery of St. Mary in Goranxi, a cultural asset located in southern Albania, as part of the MAECI mission; the project involved several local and Italian cultural institutions.

Keywords
SLAM, Digital Documentation, Structure from Motion, Integrated Survey, Built Heritage



Graphic Abstract - SLAM survey of the courtyard of the Florio factory in Favignana (TP).

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Some survey considerations

The surveying process is traditionally consolidated into two phases: the phase of acquiring information, and the phase of post-processing to conform a model on a 2D support [Docci, Maestri 1993]. These survey phases constitute the methodological basis of a process that is linked to the technological advances of the instruments used for morphological acquisition and restitution in 2D digital space. The new technologies have contributed to the articulation of methodology into the direct method, instrumental method and indirect method; a denomination that today is purely indicative, and helps to group Low and High-tech instruments whose use is increasingly integrated [Adamopoulos, Rinaudo 2019]. Advanced capturing technologies have changed the approach of the surveyor who, from being a careful selector of data useful for efficient representation, has become a massive accumulator of information [Bianchini et al. 2019]. The awareness of being able to acquire a large amount of data is changing some methodological cornerstones, blurring the boundary between the acquiring phase and the post-processing phase. The possibility of acquiring the shape of real objects by generating 3D clouds of millions of points makes it possible to have data extremely accurate, allowing the surveyor to postpone the critical analysis phase until the moment of post-processing. Some new technologies make it possible to retrieve the concept of 'survey project'; we refer to instruments inherited from robotics, which are now also used for the rapid mapping of urban spaces and landscape scenarios, i.e. Simultaneous Localization and Mapping (SLAM). Some experiments show how this solution is particularly appropriate in cases of reduced accessibility or where the use of conventional 3D surveying procedures is limited or insufficient. [Sammartano, Spanò 2018]. The thesis set exposed above found verification within the MAECI project [1], activities started in 2019 for the development and application of 'Multidisciplinary technologies for the study and conservation of three post-Byzantine monasteries in southern Albania'. The article will expose some of the activities carried out at the St. Mary's site in Goranxi.

We can imagine two opposite scenarios for survey activities: on the one hand, activities where accurate instrumentation with massive acquisition capacity is available [Bolognesi, Aiello 2019; Parrinello et al. 2018]; on the other hand, activities in which it is necessary to choose *a priori* the devices to be used. The first case involves methodological exceptions to acquire the morphological information of real objects (from architecture to the urban environment) as richly as possible. In various contexts, the information detail and the multiplicity of methods used in the survey can lead to information redundancy, to be resolved later with advanced data editing approaches [Pierdicca et al. 2020; Russo et al. 2021]. The second case is one in which the aims of the project, the difficulties due to the complexity of the site, its state of conservation and the availability of funds force an a priori choice of the technologies to be used. This condition compels a critical process typical of the survey project, aimed at the selection of the data before its acquisition, fixing tools and procedures in advance (fig. 1).

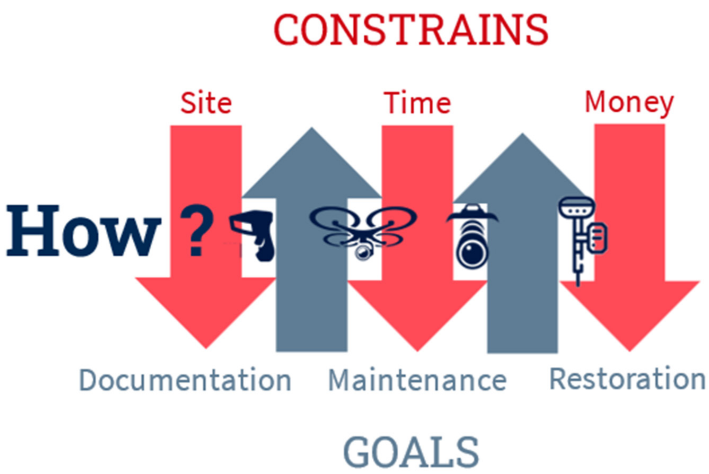

Fig. 1. Diagram illustrating the sequence of constraints and objectives that led to the choice of surveying tools used for MAECI mission surveying activities.

The survey activities of the MAECI mission in Albania are in this second case; the funds allocated for the survey allowed the planning of an eight-day campaign phase, including transfer to reach the various sites. The difficulties due to site, transport space and limited time, together with the survey objectives, led to the choice of compact and dynamic instruments for the acquisition of metric data. The project's goals require a digital survey that integrates modern techniques to develop a point cloud, able to be used as the basis of a Scan-to-BIM process [Bolognesi, Garagnani 2018; Yang et al. 2020] and to support observations on the state of conservation of masonry.

About SLAM procedure

In some cases, the classic LiDAR technology is limiting for the acquisition of areas with complex orography, with impervious subjects, partially obstructed and often covered by vegetation. In these conditions, it is necessary to use instruments that allow sudden changes in the acquisition programme, due to observations before and during the survey action.
SLAM technology responds particularly well to this type of operation, being characterised by manoeuvrable instruments (fig. 2), with reduced dimensions, enabling to move around

Fig. 2. Some laser scanners using SLAM technology. Leica BLK2GO, Kaarta Stencil 2, GeoSLAM (from left).

the complexities of ancient architectures, avoiding, as much as possible, data gaps produced by unforeseen obstacles, visible only during the acquisition phase. SLAM technology comes from robotics and allows machines to get to know places while moving: an activity that takes place in the absence of external positioning systems such as the Global Navigation Satellite System GNSS [Alsadik, Karam 2021]. There are different types of SLAM processes about the sensors that equip the sensing device: cameras, LiDAR, GNSS (receiver/antenna) and the IMU (Inertial Measurement Unit). The IMU is the main sensor that puts together data from an inertial system that takes in motion paths, distance and speed of movement; data that allows the position of the device to be identified simultaneously. This mode of measurement results in an increasing error as the distance travelled increases; the phenomenon is commonly called "drift" [Baudoin, Habib 2010]. Error reduction is achieved through the integration of data from other sensors (Structure from Motion and Lidar) but also through compensation resulting from closed survey paths (closed loops). The interest in SLAM systems also derives from the possibility of retrieving some basic concepts linked to the tradition of the direct survey: a process that allows to set up of a survey project a priori and also to efficiently select useful data in a system of complex shapes. Below are listed the procedural steps that characterise mobile mapping with SLAM, trying to create a bridge with some traditional survey concepts, to show how the link between 'tradition and innovation' allows for obtaining efficient data.

Site knowledge
The procedure requires an initial knowledge of the site for identifying viable routes and positioning topographic points along them (Ground Control Points). The points have the double role of orienting the acquired data concerning the global reference system and, in case more than one path is required, linking them together through the recognition of at least three common points. For this reason, some SLAM devices are equipped with topographical tracking systems using record topographic points along the path (GeoSlam ZEB Horizon for example) in correspondence with previously positioned targets and detected by a GPS system.

Polygonal Construction
One of the principal characteristics of traditional surveys was the need to construct a closed polygonal, with several significant points identified during the site knowledge phase, to return a relative reference system capable of correcting, once the polygonal was closed, any transcription errors of angles and measurements [Ippoliti 2000 p.109]. Similarly, SLAM processes are guided by algorithms to correct for the 'drift' phenomenon, not only through the support of additional sensors but also by 'closing the loop' (fig. 3). Closing the loop allows further refinement to achieve an overall coherent SLAM solution, particularly on long paths. This is also necessary for the presence of very precise sensors, which are also subject to instrumental uncertainty that accumulates and leads to path drift. [Lu 2022]. In

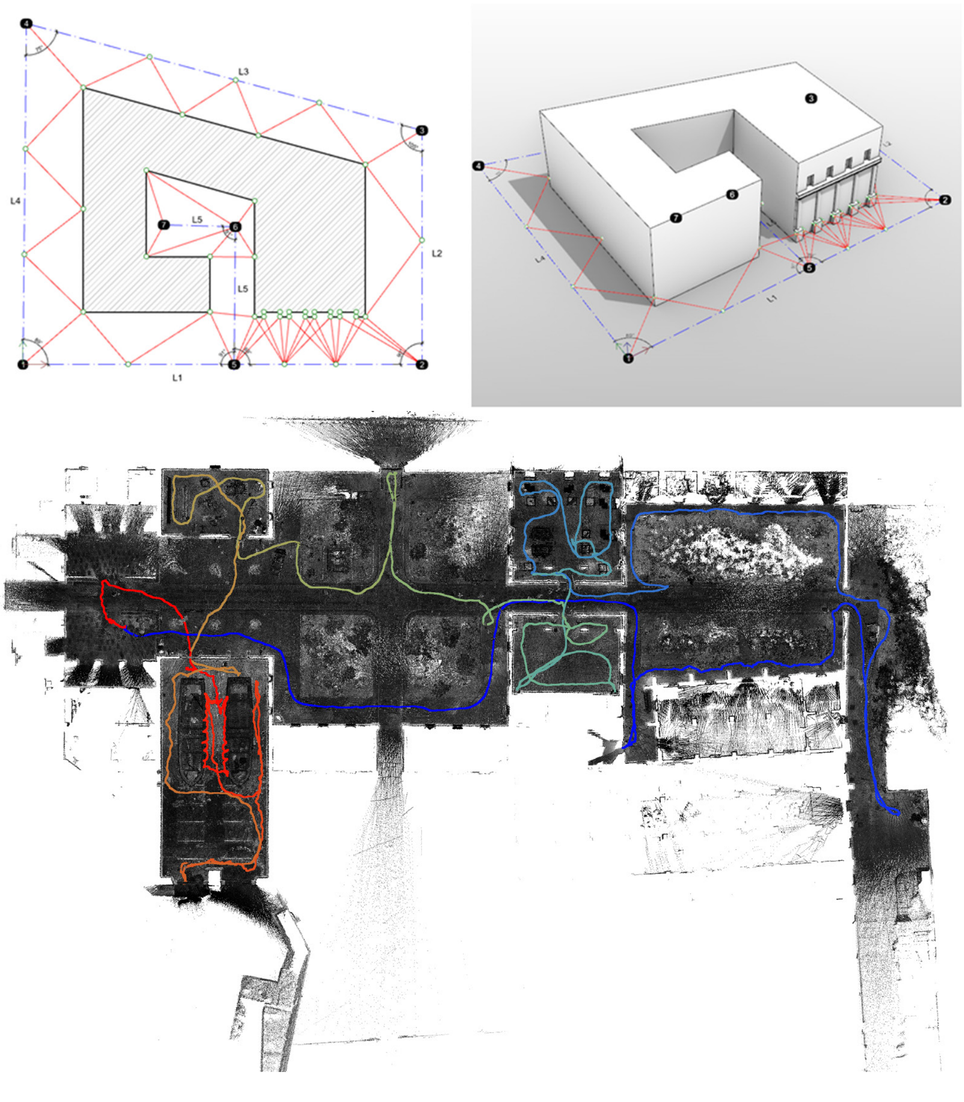

Fig. 3. Transposition of the polygonal concept from traditional topographic survey (top) to digital survey performed with SLAM technology (bottom).

the representation of the data in a digital environment, due to the accumulation of errors in the capture phase, there may be a displacement of the digital path concerning the real one, not allowing the closure of the polygonal (drift). In the editing phase, SLAM processes make it possible to force the closure of the loop by applying a corrective transformation to the points of the cloud that is gradually created during the survey process to compensate for the error. Some site conditions do not allow the creation of closed paths; in these cases, more relevance is given to contextual geometries that must guarantee an articulated and well-textured conformation, avoiding long paths.

Choice of accuracy

The technique of topographic survey using polygonal requires the identification on the fundamental line of a series of station points with which to identify chosen points on the real object; the greater the number of points chosen on the object, the greater the accuracy of the returned model. SLAM technology appears to be a link between other more accurate digital techniques, to be used in localised parts of the artefact, where a greater description of the shape and state of the artefact is desired. The described conditions highlight the importance of the preliminary definition of the level of detail to be obtained; the knowledge of the objectives and the contextual constraints allows the choice of the "survey modules", that is the additional technologies to be integrated into the SLAM process to increase the accuracy of the numerical model.

The site studied for the MAECI mission: The monastery of St. Mary in Goranxi

The complex of St. Mary in Goranxi is one of the largest in the Lower Dropull, known for its architectural and decorative richness. It stands on a large plateau, about 6 kilometres from the village of Goranxi, isolated and in a panoramic position overlooking the valley below. It constitutes a cornerstone of the local historical road network and a religious landmark (fig. 4). The church is quite completely preserved, while the structures of the monastery around are partially in a state of ruins (fig. 5). The church stands in the centre of the courtyard and it is dedicated to the Assumption of Mary. According to the inscription engraved on a stone slab above the narthex door, the church was built in 1600.

The architecture of the church appears altered concerning the probable original configuration; careful observation of the elevations shows that the forepart of the building and the narthex were placed against the façade and subsequently raised to join the pre-existing structure. This precarious condition of the building and the need to document the state of the architectural complex made it an ideal subject for an integrated survey using SLAM technology.

The tools used to collect information for the data acquisition with the different methodologies were:

- KAARTA Stencil 2 as laser scanner (SLAM), used for the description of the interior and exterior spaces of the built space;
- DJI Mavic Mini used for the description of roofs and the ground;
- Canon EOS 750D for close-range photogrammetry, used for accurate description of masonry deterioration;
- GNSS HYPE V TOPCON antennas in Base-Rover configuration, used for entering the survey data into a global reference system.

The purpose of the framing network is to set the coordinates of the points necessary to geo-reference the surveys that will be carried out using a GNSS (fig. 6). In the monastery's courtyard were placed special targets so that they could be easily identified from the aerial photographs, thus facilitating their location during georeferencing. These were supplemented with an equal number of circular reflective targets positioned in the centre to be more easily detected by the adopted laser scanner (KAARTA Stencil 2) thanks to the possibility, during post-production, of isolating the reflectance data (fig. 7). Preliminary investigations were aimed at identifying useful routes for the SLAM tool to collect as much information about the building as possible. We started the SLAM survey from the outside of the walls to

Fig. 4. Location of the site used as a case study for the integrated survey activities.

Fig. 5. The exterior of St. Mary's church at the time of the survey activities. Photos by BHiLAB - CNR ISPC.

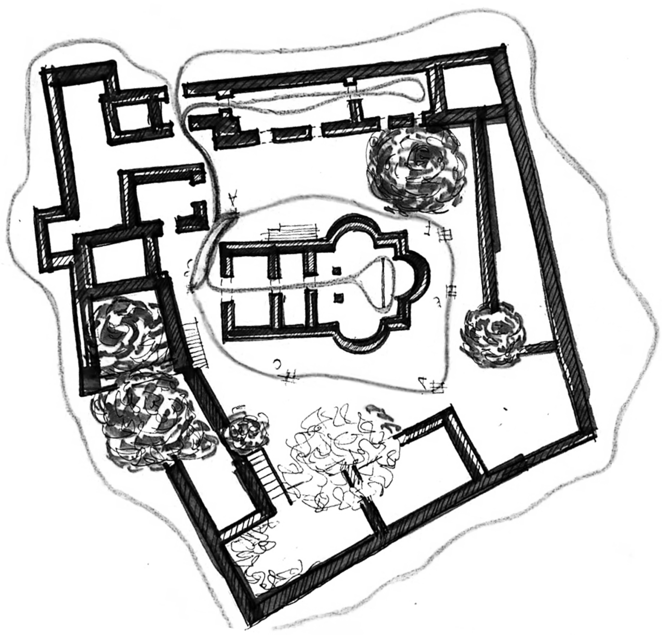

Fig. 6. Design of paths made with the KAARTA Stencil 2 laser scanner to ensure coverage of at least 3 common points and closed paths.

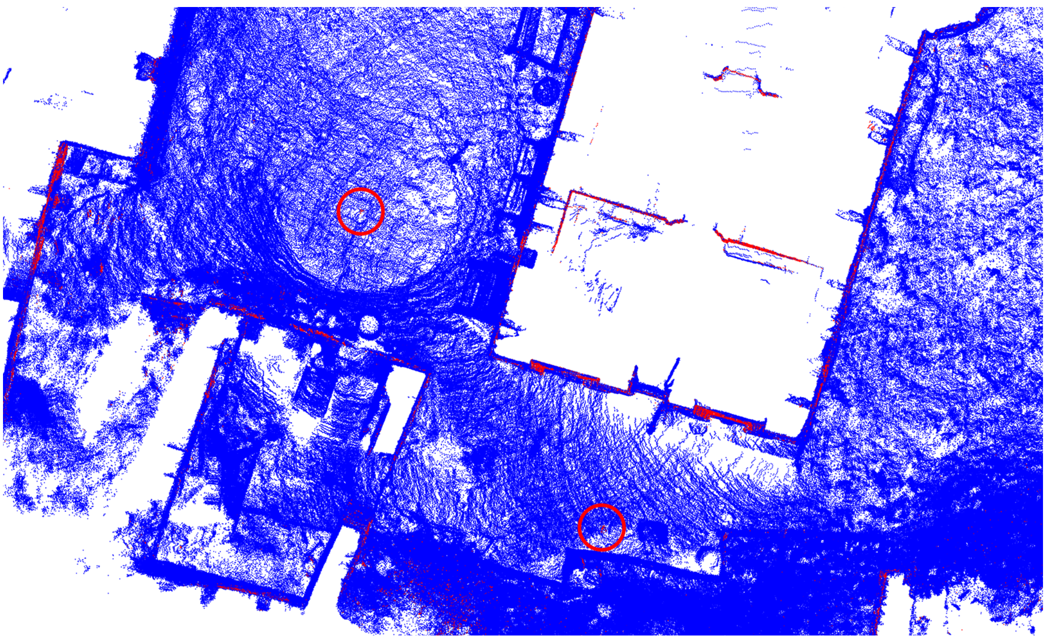

Fig. 7. The reflectance data of targets placed on the ground allows us to identify them in the point cloud.

acquire the state of the boundary wall. A second scan was carried out inside the courtyard to gather information regarding the outer perimeter of the church and the inner monastery walls. Finally, we proceeded with the acquisition of the points inside the church (fig. 8). At the same time as the SLAM acquisition phase, the aero-photogrammetric survey was carried out with the aid of a DJI Mavic Mini drone. Following the aero photogrammetric survey by UAV, we moved on to the close-range photogrammetry through a Canon 750D, which was necessary for the observation of the details on the outside of the case study and, above all, for the detailed survey of the interior of the church (figs. 9, 10). The latter activity was useful for enriching the survey of those parts of greatest interest to us, with which to carry out further digital diagnostic activities [Calvano et al. 2022; Gigliarelli et al. 2022].
The post-production of the data mainly involved the integration of the point clouds from the different methodologies. The cloud produced with KAARTA was used as the main data on which to orientate the point clouds with greater detail (photogrammetric data, more accurate and provided with the RGB value). It was produced a single SLAM cloud

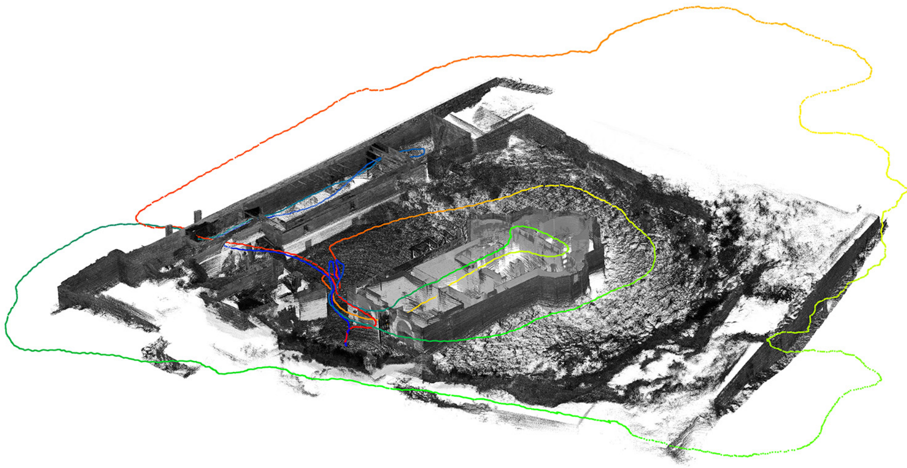

Fig. 8. Exterior and interior paths made with Kaarta Stencil 2 in the monastery dedicated to St. Mary. The paths were identified to obtain a complete cloud. The paths have common targets for the relative orientation of the clouds.

Fig. 9. St. Mary point cloud composed of UAV and close-range photogrammetric survey data.

by recognising common constellations of GCPs present along the different paths acquired; this activity allowed relative orientation between the different clouds produced by SLAM technology. Once the entire laser scanner cloud was returned, the photogrammetric output generated by Close Range processes was oriented on this (fig. 11), integrating the building elevations, the subject of further investigation. Finally, the UAV photogrammetry was used to give indications on the conformation of the roofing and ground contours, but also as a further verification tool on the global and relative orientation of the survey portions.

Fig. 10. The point cloud from the close-range photogrammetry process illustrates the vault's geometric complexity and decorative richness.

Fig. 11. Orientation process of the elevations detected by close-range photogrammetry and a point cloud from the Kaarta laser scanner. This was done manually by recognising homologous points on the two representations.

Conclusions

Applying this process to several case studies, it was possible to conceive a survey protocol based on modular technologies, with which to connect and integrate data acquired from the various survey instruments. The first procedural module involves the acquisition of the spaces through SLAM technology; the mobile mapping activity makes it possible to obtain an adequate base for the morphological knowledge of the spaces in a short time, acting as connective data for further modules useful to increase the accuracy of the data. From the SLAM data, we have the information to trigger the Scan-to-BIM process for the historical building. Depending on the technologies used, it is always possible to extract information of a topographical nature from the SLAM data to connect the cloud to a global orientation system. The connective nature of SLAM technology makes it the main procedural module, to be enriched with further modules concerning the multiple purposes of the survey. In the future, the procedure will be implemented using software and devices that allow a better colouring of the SLAM data [Cozzens 2022], remaining however within the centimetric accuracy possessed by the device. By homology, however, it is possible to connect this data to more accurate photogrammetric information coming from a close-range device or coming from a UAV, but also to the LiDAR datum of a 3D scanner. Future research developments foresee the use of numerical data for constructive HBIM modelling to expand the set of tools designed to represent a historical building [Malinverni et al. 2019].

Notes

[1] The project for the study and conservation of the Post Byzantine monasteries in southern Albania, coordinated by the ISPC of the CNR, is funded by the Ministry of Foreign Affairs and International Cooperation of Italy. The first mission occurred in 2019, while the results of this survey and investigation campaign took place in October 2021.

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