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02 September 2025

DOCUMENTATION OF COMPLEX ENVIRONMENTS IN CULTURAL HERITAGE SITES. A SLAM-BASED SURVEY IN THE CASTELLO DEL VALENTINO BASEMENT

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KEY WORDS: Cultural Heritage, 3D survey, rapid mapping, MMSs, SLAM technology, complex environments

ABSTRACT:

Underground Built Heritage (UBH) stands out among the existing Cultural Heritage sites as a peculiar scenario. The assets belonging to this type of heritage are typically difficult to manage, exploit, and promote because of a lack of knowledge and documentation. The challenges in documenting built heritage are many and wide-ranging, and the main need must be to provide an accurate and appropriate representation of the surveyed area and its geometric features without employing time-consuming processes. Mobile Mapping Systems (MMSs) are nowadays trending technologies for the geomatics community, proving to be a useful alternative to traditional surveying techniques when taking time and cost constraints into account.

The paper focuses on the use of an MMS, the STONEX® X120^{GO} *SLAM Laser Scanner* system, in documenting a portion of the Castello del Valentino, an articulated and complex architecture located in Turin (Italy). The underground floor of the castle, due to its complexity in terms of accessibility and the challenge it poses for the documentation approach, was chosen as a case study to assess the STONEX® X120GO's capabilities in terms of portability of the instrument, speed of acquisition, as well as completeness and accuracy of the acquired dataset. The results obtained using the MMS technique have been compared to and validated using data from a TLS (Terrestrial Laser Scanner) survey used as a ground reference. The results and considerations reported in this paper demonstrate that MMSs can accurately and completely depict built spaces and their main characteristics and have substantial potential in mapping complex assets.

1. INTRODUCTION

In the last few years, low-cost solutions and rapid mapping approaches have been trending topics for the geomatics community. Several efforts have been devoted to the investigation and development of these approaches for their application in several fields (Di Stefano et al., 2021). Cultural and Built Heritage documentation represent two of the domains in which the implementation of these approaches was particularly ground-breaking (Rodriguez et al., 2017, Bronzino et al., 2019).

When dealing with the survey of Built Heritage, several aspects have to be taken into consideration to thoughtfully design the documentation process: obtaining a complete, accurate, and appropriate representation of the built spaces, their geometry, and other information is the main goal. Nevertheless, the costs of the entire procedure have to be evaluated and set a priori, as well as the time required for each step of the documentation process. Architectural Built Heritage, for its own nature, is often distinguished by an articulated conformation, which leads to a need for special awareness in the design of the survey project. This includes the identification of the best solution for an adequate surface reconstruction meeting the intended purposes and final requirements of the survey. Moreover, it's not unusual for complex environments in the Cultural Heritage (CH) field of suffering from a lack of accessibility: agile and easy-to-use sensors should be preferable in order to collect the relevant amount of data avoiding time-consuming procedures (Di Stefano et al., 2021). Considering their developments, Mobile Mapping Systems (MMSs) can now exploit a large potential in mapping such complex assets: the ease of use, rapidity of acquisition, and the lowering of the costs for the instrumentation have to be considered when comparing these sensors to more consolidated approaches.

As a generic definition, an MMS can be described as a mobile survey platform based on SLAM (Simultaneous Localization And Mapping) algorithms that can concurrently map the environment and localize itself within the generated 3D map. An MMS integrates both mapping sensors, like LiDAR (Light Detection And Range) scanner and spherical or semi-spherical cameras, and navigation/positioning sensors, such as GNSS (Global Navigation Satellite System) receiver and IMU (Inertial Measurements Unit) platform. In this way, the system can provide in real-time 3D point clouds obtained by the automatic scan-to-scan registration with an accuracy of a few centimeters.

Using MMSs in the field of underground CH is essential to both resolving certain challenges related to the spatial conformation of the spaces and fully using and assessing the capabilities of these types of sensors. The potentialities of these approaches have been already partially evaluated in the scientific literature. Previous works concerning the evaluation of MMSs performances in the CH documentation can be found, for example, in: Sammartano and Spanò, 2018, Bonfanti et al., 2021, and Campi et al., 2022, where the rapid mapping approach is proposed in comparison with more consolidated ones, and then analysed and validated as an alternative solution in this domain.

However, there are still some research questions connected to the use of these systems in the heritage documentation process, in particular considering the rapid evolution of the available platforms on the market. The main goal of the presented work is thus to evaluate the use of these approaches for the documentation of complex environments in the Built Heritage domain.

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1.1 The case study: Castello del Valentino

The Cultural Heritage site of Castello del Valentino (Figure 1) was chosen as case study. This castle is a stunning architectural heritage located in Turin (Piedmont, Italy). It was built in the XVI century and became the residence of the royal Savoy family in 1564, when Emanuele Filiberto transferred the Savoy capital to Turin and then bought the castle. In XVII century, Cristina di Francia promoted the conversion of the building into *maison de plaisance* according to the French model, and the architects Carlo and Amedeo di Castellamonte conceived the construction of an impressive building by doubling the existing architectural structure.

Figure 1. View of the Castello del Valentino (Author A. Spreafico).

At the beginning of the XIX century, no longer used as ducal residence, the building housed the *Scuola di Veterinaria* (Veterinary Medicine School) and then it was employed as military barracks until it was ceded by the Crown to the State ownership in 1850. From the late forties of the twentieth century the building is owned by the Polytechnic of Turin, and now it hosts the Department of Architecture and Design. Since 1997 it is listed as Humanity UNESCO World Heritage.
Given the multiplicity of functions of use that the castle has exploited, and the subsequent alterations it has undergone over the years, the Castello del Valentino now appears like an articulated and very complex architecture, shaped around a central court. It is basically composed of two main floors (many ornamented and frescoed chambers are located on the first level's Noble Residential Floor), an attic with a pitched roof composed of a complex wooden warping, an underground floor hosting the basement of the castle (Figure 2), and four towers (one for each corner).

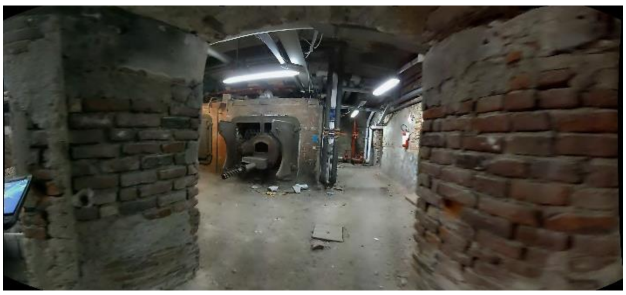


Figure 2. Panoramic view of the underground floor (obtained from the stitching of the three images acquired by the STONEX® X120^{GO} cameras).

For the purposes of this research, it has been decided to focus mainly on the underground floor for different reasons: i) it is the most complex in terms of accessibility and the most challenging one in terms of documentation approach, ii) it is under- (or even not-) documented and studied and it can provide important information about the castle history and developments, iii) it is an under-utilised and exploited part of the castle that can be valorised and enhanced in the future.
The basement asset presents a succession of rooms of different sizes and conformation, corridors, stairs, narrow passages and technical rooms, that make this built heritage a challenging scenario for testing the MMS performances (as well as other more consolidated survey techniques).

2. MATERIALS AND METHODS

The survey campaign has been carried out over a couple of days in November 2022. At the moment, for time and logistic constraints, it wasn't possible to set up a first and second-order topographic network encompassing also the underground floor. This operation is planned for the future and will represent an additional element to validate the data acquired with the MMS. In this preliminary assessment, as will be further detailed in the next sections, the data acquired with the TLS were used as a ground reference. The TLS dataset was obtained with a Leica RTC360 scanner, which main specifications are reported in Table 1.

Acquisition speed	Up to 2,000,000 pts / sec
Field of view	360° (horizontal) / 300° (vertical)
Range	Min. 0.5 - up to 130 m
Resolution*	6 mm at 10 m
Accuracy	Angular accuracy 18” Range accuracy 1.0 mm + 10 ppm
*for the considered dataset	

Table 1 Leica RTC360 main specification (https://leica-geosystems.com/en-gb/products/laser-scanners/scanners/leica-rtc360).

A total of 36 static scans have been acquired mainly in the northern part of the underground floor, plus some scans in the courtyard to strengthen the acquisition geometry. The total acquisition time was of 2 and a half hours. The TLS data were then processed following consolidated approaches inside the Leica proprietary solution (Leica Cyclone REGISTER 360) and the registration reached a final local accuracy of 4 mm (Figure 3).

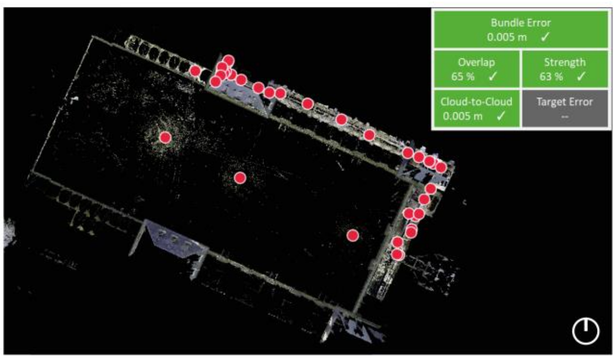


Figure 3. TLS scans acquisition scheme (red dots represent the position of the single scan) and registration error.

2.1 MMS data acquisition and processing

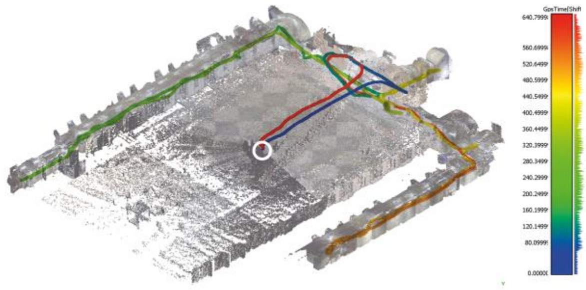
Agile and user-friendly sensors should be preferred in such vast and complex subterranean sites in order to acquire a significant amount of data without employing time-consuming procedures.
With regard to these goals, portable mapping systems allow us to: i) shorten and speed up the acquisition phase, enabling us to acquire the whole geometry of the site in less than eleven minutes; ii) better overcome the lack of accessibility and to better manage the spatial complexity of the spaces, as these systems are characterized by high portability, handling, and ease of use; and iii) collect a significant amount of dependable, quick, and ready-to-use 3D data, including both geometric and radiometric information, often without the need of a topographic support; iv) cut the costs related to the entire survey process.
The tested MMS is the STONEX® X120^{GO} *SLAM Laser Scanner* system (Figure 4), equipped with a LiDAR sensor and three 5MP cameras, capable of synchronously obtaining texture information and producing point clouds with associated RGB values, and panoramic images. The main specifications of this system are reported in Table 2.

Figure 4. The STONEX® X120^{GO} *SLAM Laser Scanner*.

LiDAR (Hesai XT16)	
Range	0.5 m – 120 m
Scanning point frequency	320,000 pts/s
Relative accuracy	6 mm
Field of View	360° x 270°
Camera	
N° of cameras	3 (5 MP each)
Field of View	200° x 100°

Table 2. STONEX® X120^{GO} *SLAM Laser Scanner* main technical specification (https://www.stonex.it/project/x120go-slam-laser-scanner).

The dataset acquired is represented by a single scan comprehensive of all the areas related to the castle courtyard and the basement (Figure 5): the acquisition started and ended in the same position, to achieve a loop closure path. As it's well known, performing a loop closure path is the best solution when dealing with this kind of mapping systems: this enables the distribution of the incremental residual error accumulated with the subsequent scan-to-scan matching (Tucci et al., 2018). The acquisition was completed by a single operator in 11 minutes and covered a small portion of the castle's courtyard and all the underground floor.
The ability to record data on the go, together with an accurate planning phase to eliminate drift errors, made field work extremely fast. In fact, it is important to underline, as in the aforementioned case, the acquisition times of the underground environment have drastically reduced compared to the TLS survey.



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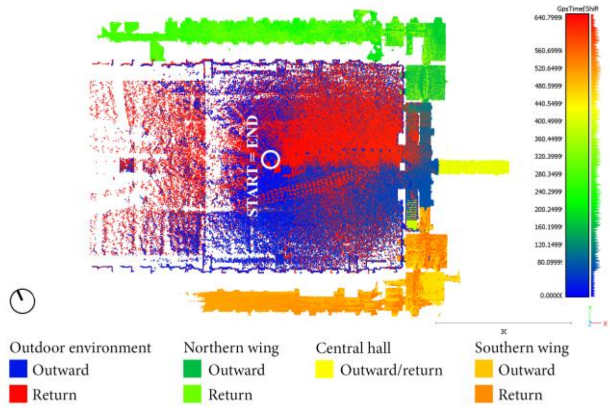


(b)

Figure 5. Path followed during the acquisition phase with tested MMS (a); the trajectory is displayed in a scalar field related to the acquisition time. Acquisition time displayed as scalar field on the MMS point cloud (b). Values are expressed in seconds and the white circle states the start and end point of acquisition.

Data processing has been completed following two separate phases. The first phase has been achieved using the dedicated software for the STONEX® MMS: GO*post*, to complete the first optimization of data with the standard workflow (Figure 6).

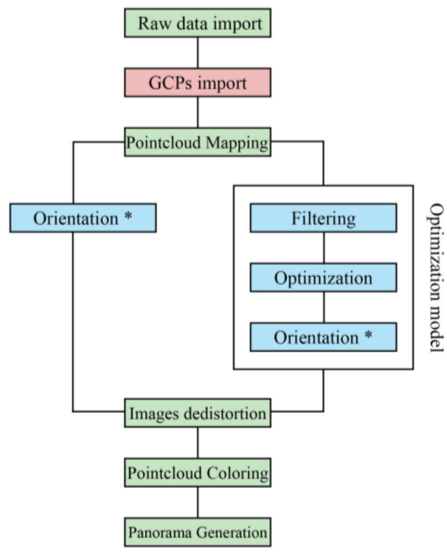


Figure 6. The followed workflow of the post-processing phase, as suggested by the STONEX® X120^{GO} *SLAM Laser Scanner* user guide. *The Orientation phase has been conducted throw the Cyclone REGISTER 360 software.

There are a few parameters that the user can customize inside this software to optimize and reprocess the data acquired in the field. A re-computation of the acquisition trajectory thanks to the IMU/LiDAR data is thus possible to re-map the recorded assets in a more accurate way. Other processing options that have been considered are related to the possibility of applying different filters such as pedestrian removal, denoising or thinning. Finally, the point cloud is colored thanks to the RGB cameras information and a general optimization (outliers and double surface cleaning) is performed.
An optional operation is connected to the cameras data processing (i.e., stitching and creation of the panoramic images).
Following this first phase, the MMS point clouds have been georeferenced to the same reference system of the TLS data to further proceed with the data analysis and validation. The main results are reported in Table 3.

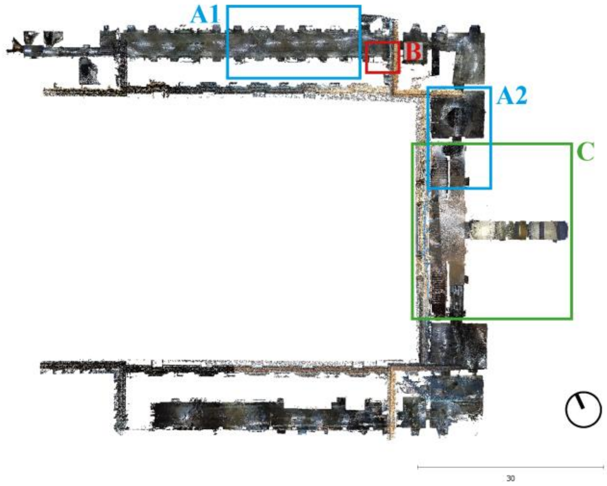
	Acquisition time [min]	N° of points	Elaboration time [h]	ICP RMSe [cm]
STONEX® X120GO dataset	~ 11 min	28 721 056	1:10	1.2

Table 3. Principal results regarding the acquisition and the post-processing phase, the ICP registration has been conducted throw the Leica Cyclone REGISTER 360 software.

The obtained dataset is the optimized point clouds containing data both of the courtyard and the basement. As we were interested only in the underground floor environment, the point cloud has been filtered and segmented according to the acquisition time, in order to automatically obtain a subsample of the entire dataset. Thereafter, since the TLS ground truth had been acquired only for the northern part of the basement, we reprocessed the STONEX® X120GO point cloud in order to obtain two comparable datasets.

3. DATA ANALYSIS AND VALIDATION

It is widely acknowledged, as previously mentioned, that documenting and modelling CH is a complex task, driven by several factors. This complexity is demonstrated by the diverse requirements and comparisons that CH products must meet. Therefore, it is crucial to establish validation criteria that address metrics of quality and other parameters related to dataset usability. Additionally, it is essential to consider the application of these datasets through a representative sample that accounts for the unique characteristics of cultural complexes.
The 3D point cloud obtained using the MMS has then been examined and evaluated following both quantitative and qualitative analysis.
We defined three different tests area to perform the analysis (Figure 7): A) two sample areas of the north wing, in which we tested the general performance of the MMS, evaluating the point cloud accuracy and precision with the C2C (Cloud to Cloud) distance analysis; B) on a single wall with different geometric and material characteristics (a plaster part, a part with exposed bricks, and an opening with an iron gate), to perform a local evaluation of the point cloud taking into account: density, noise level, presence of outliers, details and geometric features recognizability; C) the entrance portion of the underground floor: here we compared the results of different post-processing approach. Furthermore, we defined two other areas (D) where cross-sections where semi-automatically were extracted.



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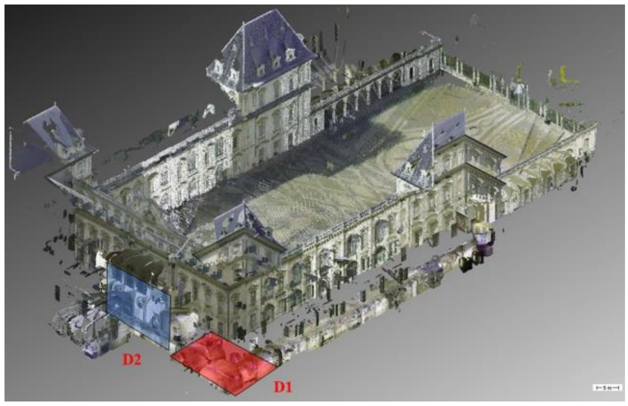


(b)

Figure 7. The three areas chosen as sub-blocks to perform different kinds of analysis (a) and cross-sections position (b).

3.1 A. C2C analysis

The first analysis carried out on the SLAM point cloud after the processing was a C2C analysis on two selected sample areas (Figure 8). The TLS dataset was used as a reference (with a maximum allowed distance analysis of 0.1 m, in order to exclude possible outliers). Moreover, the choice of threshold adopted for this analysis was related to the general accuracy requested in the CH survey. The C2C analysis was achieved using the Leica proprietary software Cyclone 3DR. The results of this analysis are reported in Figure 9 and Table 4.

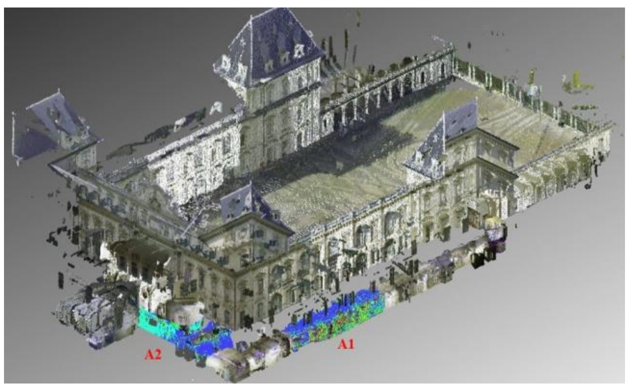
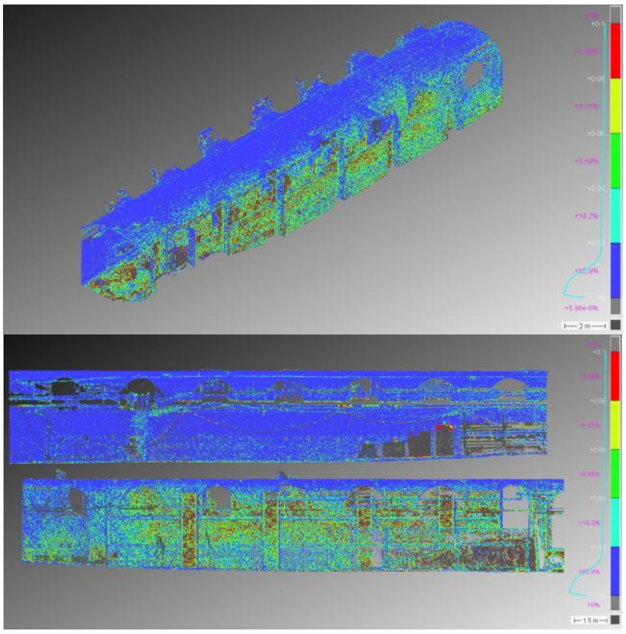


Figure 8. Position of the sample areas (A1 and A2)



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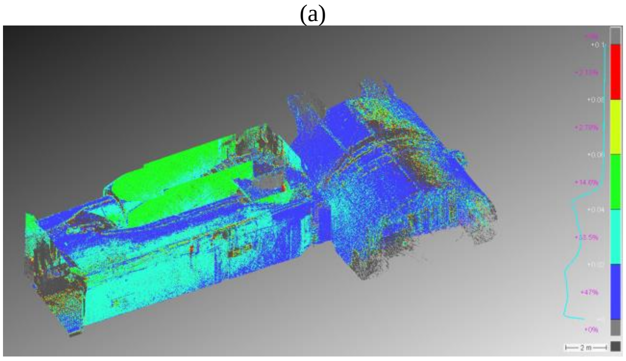


(b)

Figure 9. C2C analysis on sample area A1 (a) and A2 (b)

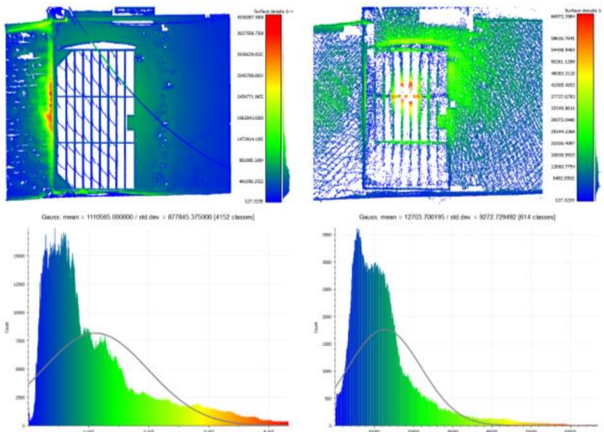
C2C	<0.02 m	0.02–0.04 m	0.04–0.06 m	>0.06 m
A1	66%	14%	10%	10%
A2	47%	33%	15%	5%

Table 4. C2C analysis distribution on different range of value for sample areas A1 and A2

From the C2C analysis is already possible to start drawing some conclusions. In the sample area A1 the SLAM system is performing slightly better in comparison with the TLS dataset with the 80% of point under 0.04 m (the conventional tolerance for a nominal representational scale of 1:100). In the case of dataset A2 this percentage is the same (80%) but with a different distribution in the considered threshold, especially with a higher number of points in the range comprehend between 0.02 and 0.04. m. Moreover, in the scalar field representation derived from the C2C analysis and reported in Figure 9, it is possible to highlight some systematic errors for both sample areas. This is particularly evident in some ranges of values: the one comprehends between 0.02 and 0.04 m (represented in light blue in the images) and the one between 0.04 and 0.06 m (represented in green in the images) that are mainly located in the same areas. This may be ascribed to several factors such as the acquisition strategy, the data processing of the SLAM, or the georeferencing of the point cloud and it's a theme that needs to be further investigated.

3.2 B. Features analysis

The purpose of this analysis was to evaluate the geometric characteristics and the quality of the obtained scans from a local-scale viewpoint. As a result, many quantitative and qualitative parameters have been studied in this phase, focusing only on a sub-dataset (sample area C). At a local level, the STONEX® X120^{GO} dataset completeness and quality have been assessed. The values of density and roughness have been locally computed for selected test areas in order to evaluate the capability of the system to properly reconstruct all the geometric features of the documented spaces. For the density analysis, for each point of the dataset, we considered the number of neighbours within a sphere with a radius of 0.02 m. The level of noise has been locally analyzed using the "roughness" mathematical algorithm: for each point, the nearest neighbors are taken into account while computing the best-fitting plane; the roughness value is defined as the mean deviation of each point from the estimated plane; also in this case, a sphere with a radius of 0.02 m has been taken into account. The main results of this analysis can be seen in Figure 10 and Table 5.



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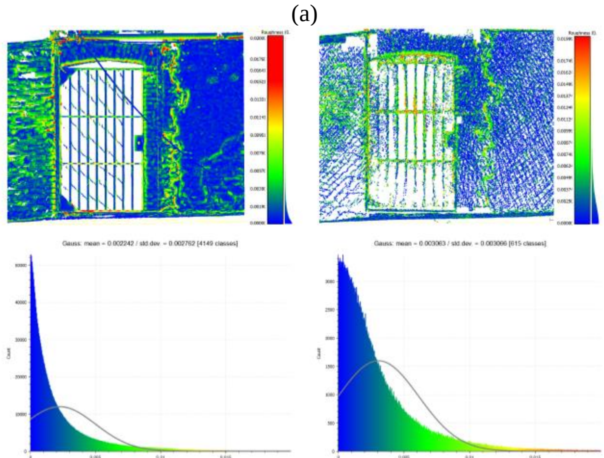


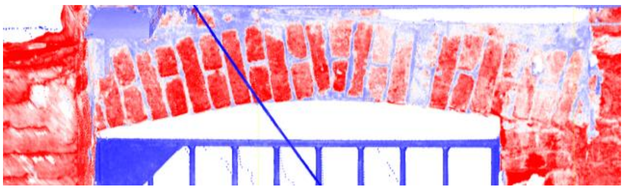
(b)

Figure 10. Density (a) and roughness (b) evaluation results. On the right the TLS dataset, on the left the SLAM one.

	Density*	Roughness*
SLAM	12 703	0,004
TLS	1 110 565	0,002

Table 5. Results of the analysis performed. *The values of density and roughness are referred to a sphere with a radius of 2 cm.

Also for this analysis it is possible to report some first consideration. Concerning the results of the density analysis it is clear, as expected, that the point cloud's density is strongly correlated with the acquisition distance between the sensor and the object being acquired, and as a result, with the operator's trajectory and the amount of time it took to acquire the surveyed surfaces. Looking at the results of the roughness analysis, it is evident from Figure 10 (b) that the level of noise is greater when compared to the traditional TLS data. The mean roughness value obtained in this case is up to ~4 mm for the MMS dataset and ~2 mm for the TLS one.
The level of noise is generally associated to the stability of the system at the scanning time, so it is deeply influenced by the operator capability in maintaining a stable attitude all over the acquisition. Finally, for the feature recognizability, it needs to be considered that when mapping CH for representational purposes at the architectural scale (1:100/1:50) it's mandatory to evaluate also the capability of the employed system to properly reconstruct and display the geometric features of the documented asset. As it can be seen in Figure 11, in the matter of masonry walls (in this particular instance, a brick lintel) the point cloud obtained by the STONEX® X120^{GO} system only partially meets this requirement, but the density and quality of the dataset still allow to support different conventional architectural representational scale.



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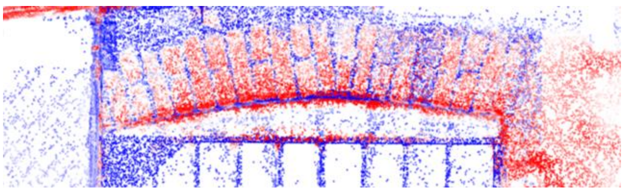


(b)

Figure 11. TLS (a) and MMS (b) point cloud extract. The recognizability of the bricks varies a lot between the two examples.

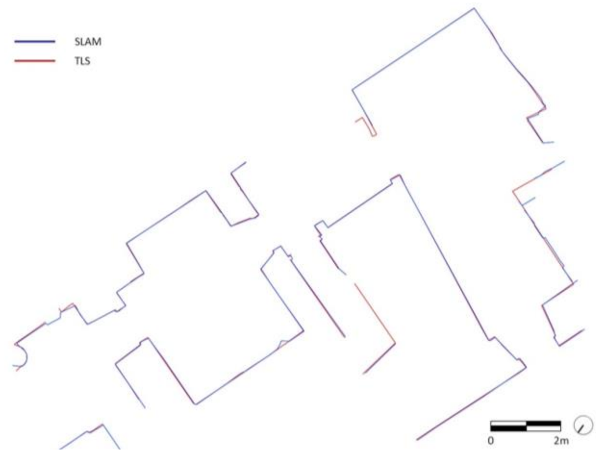
A qualitative radiometric evaluation of the MMS point cloud has also been performed. In places with such a poor and discontinuous illumination, obtaining a "good" colorimetric output is neither simple nor undervalued. Obviously, the quality of the camera between the STONEX® X120^{GO} (3 x 5MP) and the Leica RTC360 (3 x 12 MP) has the greatest influence in how the radiometric data is acquired and then displayed (rendered). Also, the number of points that describe the geometric features and the distribution of the points themselves deeply influence the rendered visual quality. In Figure 12 it is possible to observe the difference between the two datasets in terms of radiometric quality. Considering the difference between the instruments sensors, the challenging environment in terms of illumination and the fact that this kind of MMS introduced the RGB component only in recent times the results achieved by the tested SLAM can be considered satisfying also in the field and for the purposes of CH documentation.

(a) (b)

Figure 12. Visual radiometric comparison among the TLS (a) and the MMS (b) datasets.

3.3 C. Cross sections analysis

Finally, for the last analysis cross sections have been extracted from both TLS and SLAM point clouds to evaluate the ability of the MMS in reconstructing the geometrical features of the asset and which is the maximum architectural representational scale that it can sustain. Both horizontal and a vertical sections have been extracted (the position of the sections is reported in Figure 7-b) using the PointCab software and then vectorialized in CAD. This approach was followed to see how the SLAM system was able to deal with the traditional 2D representations that are generally requested in the CH and architectural fields.



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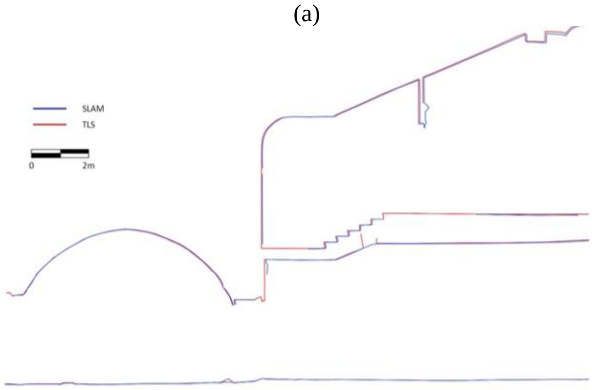


(b)

Figure 13. 2D sections derived from the SLAM and TLS point cloud: horizontal section (a) and vertical section (b)

In Figure 13 the 2D sections extracted and vectorialized are reported. The results of this analysis are in line with the ones already reported for the C2C and features analysis. The deviations between the section extracted from the TLS and the SLAM point clouds are limited (generally in the order of 2 to 4 centimeters and the two datasets are generally overlaying. Regarding the completeness and the level of detail the TLS is, as expected, having the upper hand; however the SLAM point cloud was able to represent all the major features of the assets and the missing data are limited to smaller portions or details.

3.4 Different post-processing approach analysis

Additional tests have been carried out within the post processing phase, to evaluate how different data elaboration approaches can influence the result. Since the STONEX® X120^{GO} dataset had been already compared with the Leica RTC360 one, within this set of analysis no TLS data has been employed as ground truth. Different post-processing strategies have been performed and the results have been compared one to each other.

Considering only the Area C, the same raw point cloud has been re-processed five different time, changing from 1 to 5 the "Stability" parameter. This parameter is referred to the degree of variability of the scanning scene: for indoor environment is preferable to use the Stability parameter set as 5, 3 or 4 has to be used for mixed environment, 1 or 2 for outdoor and widely various scenarios (STONEX® X120^{GO} *SLAM Laser Scanner* User Manual).

Since stability isn't an objective parameter, most of the decision-making is left to the operators' experience. As a result, it can be difficult to set a priori the "best" value for this parameter.

When reprocessing using different Stability values, the IMU trajectory is recomputed at various speeds and levels of accuracy, and the resulting re-mapping of the spaces documented by the LiDAR sensor goes through various degrees of filtering and optimization. This causes the major differences between the five tested workflows and influence the processing time of the point clouds (Table 6).

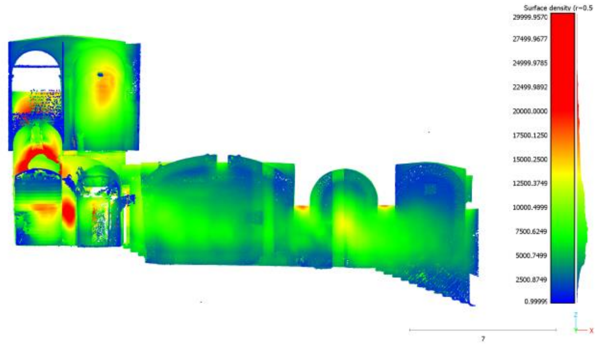
Dataset	Elaboration time [h]	N° of points	Mean thickness [cm]
Stability 1	3:23	27 000 985	2
Stability 2	2:27	27 408 976	2
Stability 3	1:49	28 622 219	3
Stability 4	1:30	28 743 436	3
Stability 5	1:11	28 828 742	3

Table 6. Influence of the Stability parameter in the post processing phase of the Dataset. With low values of Stability the elaboration time significantly increases, the final optimized point cloud undergoes a more aggressive filtering and thinning operations and therefore has a lower number of total points.

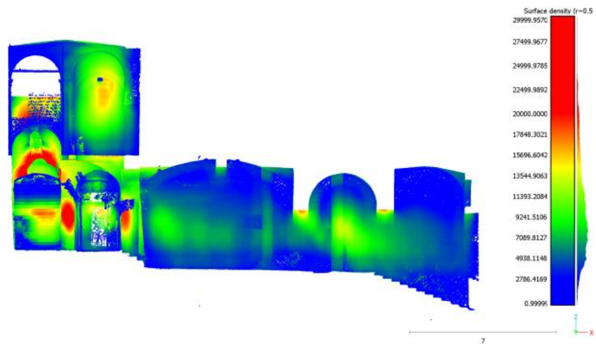
As a generic consideration after this preliminary analysis, it has to be said that most of the time balancing elaboration time and final accuracy is the best solution when dealing with these kind of mapping systems. However, it is crucial to take into account how, within the same acquisition path, the different degrees of cloud processing might affect the final result, and it is worthwhile performing further analyses.

Regarding the evaluation of the obtained datasets, the values of density and roughness have been computed and compared to each other. Furthermore, a visual comparison along horizontal sections has been accomplished, to roughly detect the greater discrepancies between the five datasets.

Density values vary from a minimum of 7'768 (with Stability set as 1) to a maximum value of 11'150 points/m^2 (with Stability set as 5). Although usually having a higher density means having a higher quality of the point cloud, in the case of STONEX® X120^{GO} datasets it usually coincides only with a greater number of points, but they could be outliers or noise. As we can see in Figure 14, the Stability 1 point cloud (a), despite having a lower density value, it has a better and more homogeneous point distribution.



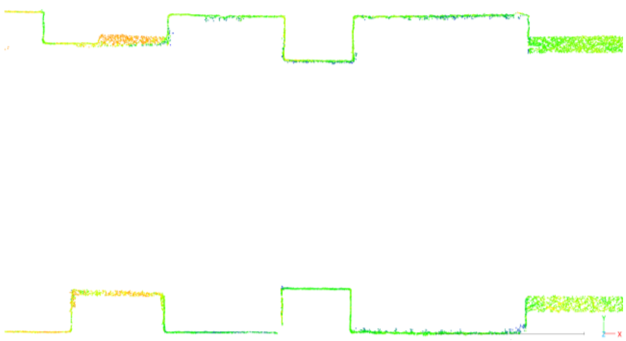
(a)



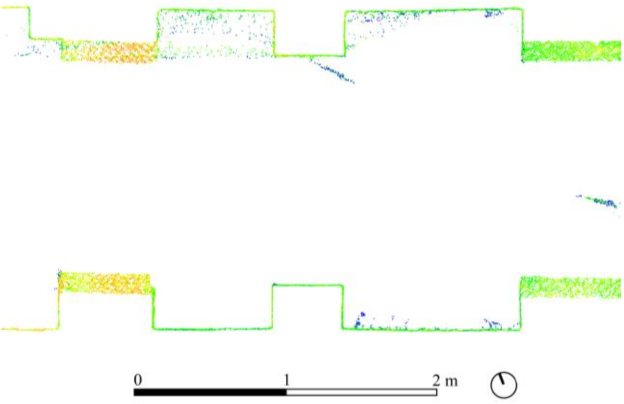
(b)

Figure 14. Depiction of the density value computed for the point cloud computed with Stability value set at 1 (a) and 5 (b).

Regarding the noise level belonging to the different processed point clouds, within this particular subset of the entire acquired data (Area C) the roughness value computed with CloudCompare (CC) is not very variable (from 0,002 m to 0,003 m). However, some differences have been underlined between the extracted profiles (Figure 15): according to the value imposed to the post-processing parameters, the raw point cloud undergoes different levels of optimization, that correspond to distinct degrees of denoising, filtering and moving object removing. These differences are appreciable even at a rough visual examination of the data.



(a)



(b)

Figure 15. Comparison between the extracted profiles of the Stability 1 (a) and the Stability 5 (b) point clouds. The presence of noise, outliers, and moving objects in the second dataset is displayed in blue colour.

4. DISCUSSION AND CONCLUSIONS

The outcomes of the tests presented in this work underline the advantages of using handheld systems in documenting CH complex assets (i.e. portability and easiness-to-use of the sensor, rapidity of the acquisition phase, quality of the geometrical reconstruction, etc.).
The presented overall evaluation of the acquisition and processing of data highlights promising results when compared with TLS data. The different analyses carried out allowed to validate the accuracy of the SLAM point cloud under different perspectives. The C2C analysis and the 2D cross-sections confirmed an overall good performance of the instrument in comparison with the TLS ground truth. The X120 data are able to sustain the typical architectural representational scale in a range between 1:100 and 1:200 both in terms of geometrical accuracy and level of detail.
Also at the local level, the mobile system attitude in reaching a discrete quality in displaying and representing the documented environment suggests that it has indeed met expectations. Achieving a good local quality suggests that the tested mobile platform is able to adapt to changes in the environment and provides accurate representation even in different contexts. The features analysis confirmed the latter statement, especially in the CH documentation domain where the possibility of representing material differences and small details is crucial.
Like with any other more consolidated survey technique, the planning phase is the most crucial one: with the right acquisition scheme (in this case, the acquisition path), the final product will obviously have better characteristics in terms of precision/accuracy as well as quality and data completeness. Moreover, also the processing phase as shown in section 3.4, can have an impact on the final point cloud and is thus an aspect that needs to be further investigated. More tests are needed and planned to enhance both the acquisition strategies and the post processing approach.
Further analysis will also be carried out in the same test field to assess the possibility to use the acquired GCPs (Ground Control Points) within the orientation phase. The STONEX® GO*post* software allows to perform both a rigid and non-rigid transformation: in non-rigid transformation, GCPs are used in the elastic compensation of the point cloud. This will permit to improve the final accuracy and hopefully to solve the georeferencing of the data inside the instrument's proprietary solution without the need of using third part software.

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