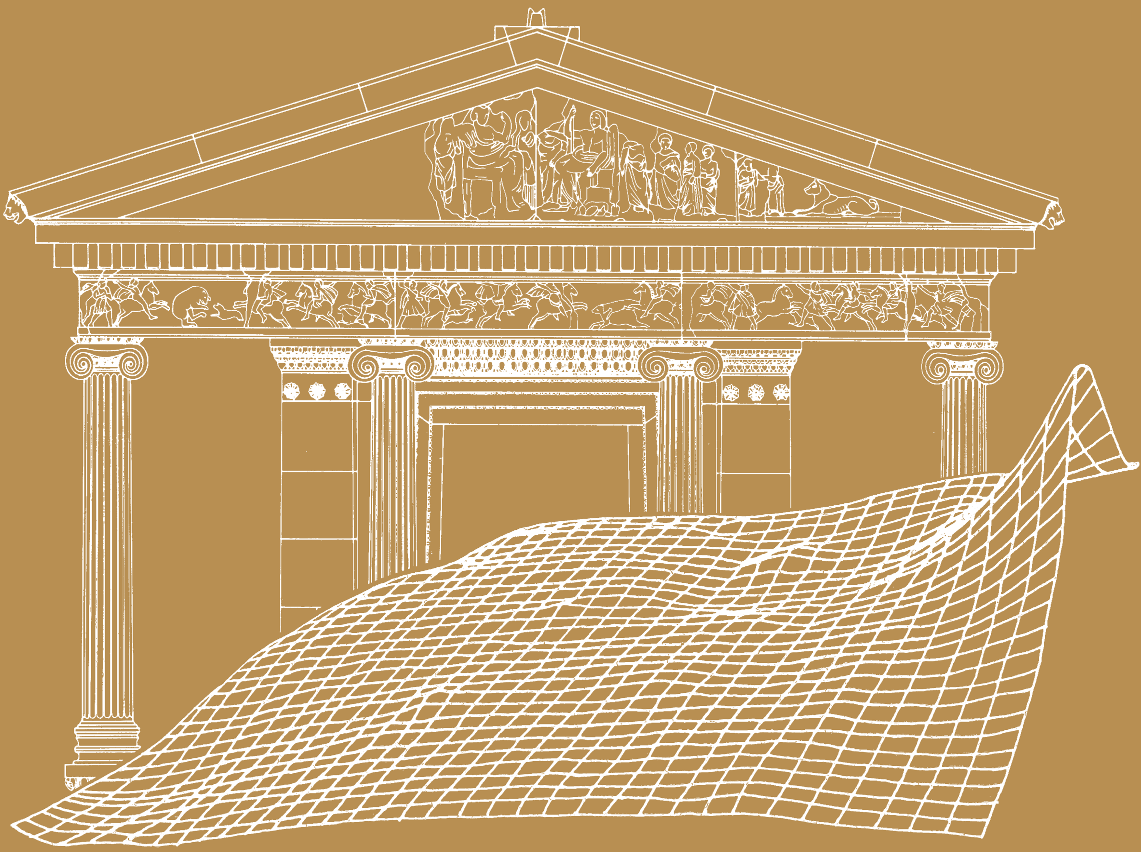

ARCHEOLOGIA E CALCOLATORI

34.2

2023

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INDICE

IN RICORDO DI LEA FROSINI ARIANI, UN EDITORE LUNGIMIRANTE

La notizia della scomparsa di Lea Frosini Ariani il 23 dicembre 2022, alla vigilia di Natale dello scorso anno, ci ha colti di sorpresa e ci ha lasciati smarriti di fronte alla perdita di una delle protagoniste della nascita e dello sviluppo editoriale di «Archeologia e Calcolatori».

La "Signora Lea", con la sua presenza costante, silenziosa ma rassicurante, è entrata nella storia della nostra rivista nel 1989, circa un decennio dopo il suo incontro con Riccardo Francovich e l'avvio di «Archeologia Medievale». La riunione per definire gli aspetti del nuovo progetto editoriale di una rivista internazionale dedicata all'informatica applicata all'archeologia riporta alla mente un'atmosfera di generale entusiasmo: le personalità volitive e dinamiche di Mauro Cristofani e di Riccardo Francovich, un gruppo di giovani studiosi a cui affidare la direzione e la redazione, un editore dotato al tempo stesso di professionalità e di umanità, pronto ad aprirsi ad ambiti meno noti ed esplorati del sapere, e un'ansia costruttiva di raccogliere presto i frutti di quanto si sarebbe seminato.

Ricordando Riccardo Francovich, Lea Frosini Ariani aveva voluto intitolare il suo saggio "A come Archeologia, A come Avventura", tenendo a precisare che il termine avventura non era genericamente legato alla professione dell'archeologo, quanto piuttosto al «partire alla ventura» di Francovich nell'«affidare la gestione di Archeologia Medievale ad una casa editrice nata da poco, quasi per gioco». Nel nostro caso, dopo solo un decennio, la situazione si era capovolta, perché le Edizioni All'Insegna del Giglio erano ormai una casa editrice affermata nel settore dell'archeologia, mentre la tematica da noi proposta costituiva per i Paesi europei gravitanti intorno al bacino del Mediterraneo, e in particolare per l'archeologia di epoca storica, un aspetto della ricerca ancora in fase embrionale. Se oggi volessimo ricalcare quel titolo, lo potremmo così concepire: "I come Informatica, I come Innovazione", dando a quest'ultimo termine anche una connotazione di Interdisciplinarità.

C'è un'altra delle tante tappe del percorso ultratrentennale di «Archeologia e Calcolatori» che giova ricordare a testimonianza della generale attenzione verso l'innovazione da parte di Lea Frosini Ariani e della sua solida convinzione che per lo sviluppo della scienza fosse necessaria una continua mediazione editoriale. Nel 2005, a soli due anni dalla Dichiarazione di Berlino sull'accesso aperto alla letteratura scientifica, la rivista, sempre pronta a sperimentare nuove vie di diffusione delle conoscenze, decise di aderire all'iniziativa proponendo un modello editoriale oggi noto con il nome di "diamond open access". Se tuttora si discute sulla fattibilità o meno di tale modello anche a livello europeo, dove proliferano infrastrutture e progetti dedicati a questa problematica, è eccezionale la lungimiranza che ha contraddistinto le Edizioni All'Insegna del Giglio. E ciò anche grazie al ruolo del figlio Tommaso, che Lea Frosini Ariani aveva chiamato ad affiancarla fin dalla fine degli anni Novanta, assai sensibile alle innovazioni del digitale e della comunicazione multimediale. Pare ancora incredibile aver trovato vent'anni fa una sponda proprio in un editore indipendente.

Per questo e per tanti altri ricordi di un lungo sodalizio scientifico e umano, la rivista «Archeologia e Calcolatori» si stringe con gratitudine e affetto nel ricordo della "Signora Lea", che è stata per tutti noi un esempio trainante di intelligente operosità e rigore.

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THE DOMUS OF THE CALENDAR: A QUALITATIVE COMPARISON ANALYSIS OF DIGITAL DATA OBTAINED FROM 3D LASER SCANNERS, SFM METHODOLOGIES, AND PORTABLE DEVICES

1. Introduction

During the last decades, digital survey technologies have been developed at a high rate. This has allowed the production of new instruments and assets to acquire high quality 3D digital geometric and radiometric data of high quality. One of the most interesting improvements of these developments is the possibility of creating realistic and interactive virtual models that accurately reflect physical objects and the dynamics of a physical system (digital twins). The ability to control an accurate replica of the continuum of three-dimensional space (with accurate geometric and chromatic data) expanded the knowledge of Cultural Heritage (Dellepiane *et al.* 2013). This innovative data acquisition paradigm was well received in architecture and archaeology for surveys elaboration, due to its ability to provide reliable graphic support for different types of research, opening new perspectives and opportunities (Ferdani *et al.* 2022). The new digital survey methodologies started to substitute traditional data acquisition instruments (such as direct surveys) because of their versatility and capacity to register extremely accurate data.

Additionally, digital data acquisition instruments allow fast acquisition data-loads and postpone data selection for the restitution phase. This kind of flexibility consents to the application of the acquired data for different purposes that can change over time (Bianchini *et al.* 2016). Nowadays, the most widespread instruments for collecting three-dimensional high-resolution digital data on Cultural Heritage are range-based instruments (such as laser scanners) and image-based instruments (such as high-resolution digital photogrammetry integrated with automatic image elaborations) (Remondino *et al.* 2008, 2014; Remondino 2011). Recent developments in range-based instruments have brought low-cost, and faster data acquisition technologies; for instance, the latest hardware by Apple uses LiDAR and TrueDepth cameras for 3D scanning. Fiorini 2022 provides a review of this technology and an evaluation of its capabilities applied in different architectural and archaeological contexts; Vogt *et al.* 2021 on their part, provides an analysis of its limitations.

In this wide range of possibilities, choosing the most suitable methodology and technology represents a fundamental aspect of determining the qualitative level of the survey. A comprehensive evaluation must consider

Fig. 1 – The Basilica of Santa Maria Maggiore (photo Juan Camilo Arias Tapiero).

different factors, such as the geometrical and physical characteristics of the research object (minimal dimension of detail, bulk, and volume, presence of translucent, mirroring, or darker surfaces, uniform superficial finishing), survey condition (accessibility of the case study), the goals of the restitutions, and the survey instrument's characteristics (accuracy and margin of error, geometric and radiometric resolution, frame field and work distance, etc.).

In Cultural Heritage, because of the wide range of case studies with peculiar and unlikely recurrent characteristics, it is possible to determine an optimized procedure adaptable to the characteristics of the subject. Several experiences of digital three-dimensional high-resolution surveys have shown that, depending on the survey objectives and communication scopes, integrating different survey techniques is the best approach for exploiting the potentialities of each instrument (Ippolito, Bartolomei 2014; Russo, Manferdini 2015; Inglese, Luchetti 2022).

The integrated survey project of the Basilica of Santa Maria Maggiore was conceived under this premise, as part of a more extensive project dedicated to the definition of a system of integrated models, which was also implemented in the Basilicas of Santa Maria in Trastevere and San Pietro, in Rome (Bianchini *et al.* 2022). This system was developed to explore the possibilities of integrating different survey technologies, for the whole purpose of using the potentialities of various instruments. The implementation of this system in the Basilica of Santa Maria Maggiore allowed us to build a global model of the entire complex to propose a new reading of the context analyzed while maintaining the data from the urban to a multi-scalar level of detail. This was also the first time that a survey of the whole basilica complex was done; the main body, the archaeological site, and other features in the underground and the upper levels were systemized as a single element of unique historical value. The model thus obtained was subsequently used as a research tool for different study purposes. The survey takes on special importance as the most recent survey of the basilica complex dates from the 60's.

The present paper introduces the most significant results obtained from the comparison of three different survey instruments: the laser scanner (Leica C10 and FARO Focus), Structure from Motion (SfM), and and the iPad LiDAR camera. The results of the comparison analyses exposed here are the ones carried on the Domus of the Calendar, that is, the archaeological site located underneath the basilica which acts as a structural foundation element of the *domus*-basilica complex. The implemented methodology is not limited to this specific case of study, and it can be replicated wherever it is necessary to evaluate the quality of the data obtained from an integrated survey.

2. The Domus of the Calendar

The archaeological remains of the Domus of the Calendar are situated under the Basilica of Santa Maria Maggiore. The basilica is located on the Esquiline, one of the seven ancient hills of the city of Rome. It is one of the four papal major basilicas and the most important religious building dedicated to the worship of Mary (Steinby 1996). The basilica was included in the UNESCO World Heritage List together with all the Holy See's extraterritorial properties in 1990 (Unesco 2021) (Fig. 2). The history of the basilica dates to Pope Liberius (352-366), who started the construction of a church on the highest point of the Esquiline hill (Steinby 1996). The former basilica, known as the Liberian Basilica, seems to have been demolished during the invasion of Rome by Alarico I in 410 AC (Liverani 2013). It is still not clear if the present basilica was initially erected by Celestine I (422-432) or by Sisto III (432-440) (Liverani 2010), but it was built in the same place where the Basilica Liberiana was located. The new church was consecrated to Mary the Holy Mother of God, a decision highly influenced by the Ephesus council's results.

During medieval times, the basilica suffered many interventions, such as the addition of a series of small churches and the reconstruction of the apse (De Blaauw 2015). During the Renaissance and the Baroque, the basilica went over a series of important additions that configured its present appearance. In this period, some of the most important architects in the history of Rome took part in the construction, such as Michelangelo, Domenico Fontana, Bernini, Ferdinando Fuga, and Carlo Rainaldi.

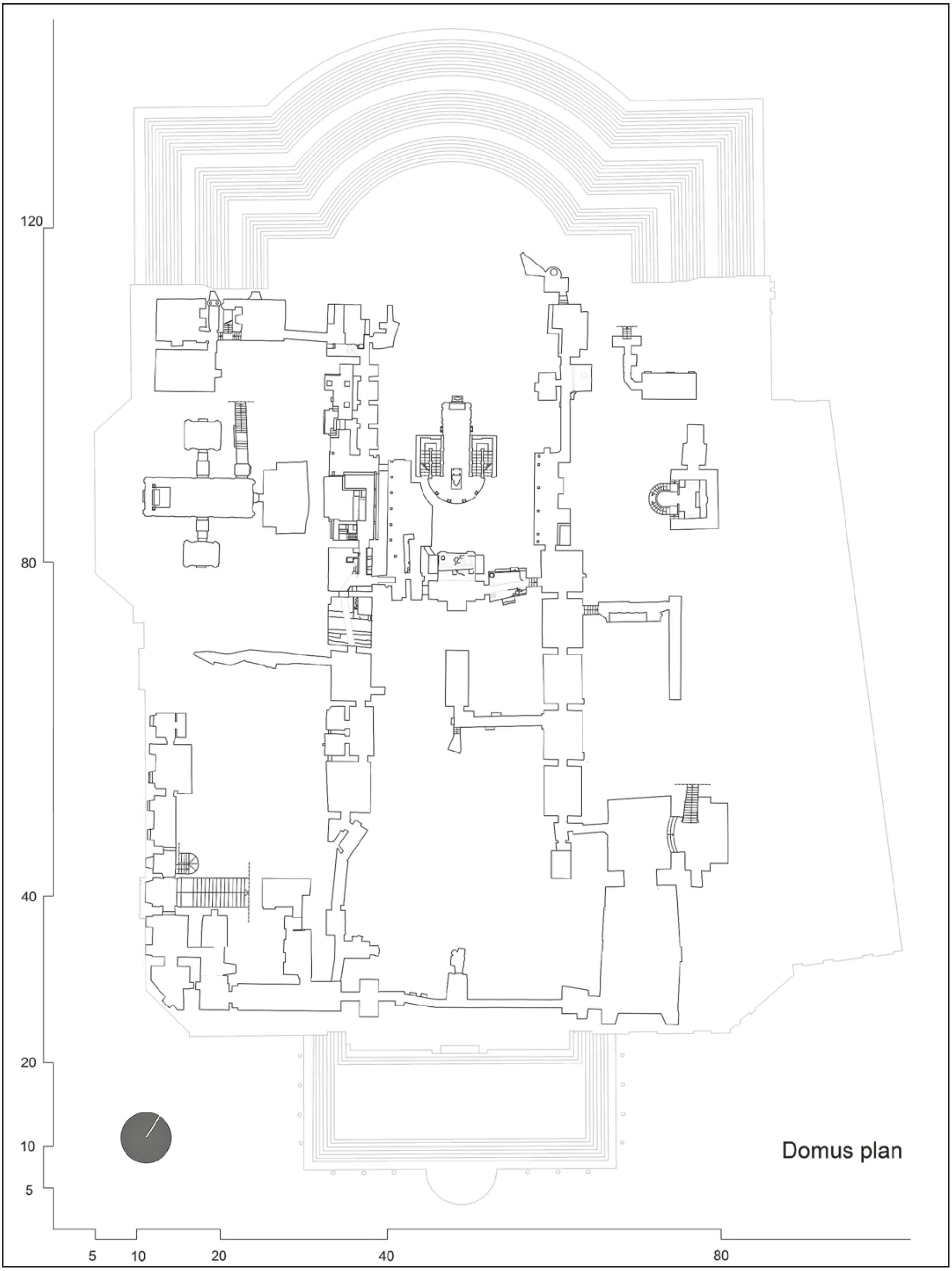

Fig. 2 –The archaeological remains located under the Santa Maria Maggiore Basilica. Plan obtained by laser scanner point cloud.

The archaeological remains located under the Santa Maria Maggiore Basilica were found in 1966 during a series of works aimed at isolating the basilica's ground floor from the soil moisture (Magi 1972). Through this process, the excavations revealed the existence of a Roman building. The most particular findings were the discovery of an exedra, as well as many frescos and mosaics. Among the frescos, it is interesting to note the discovery of a calendar painted on a wall of the Roman building, used as a foundation for the basilica. F. Magi identified the archaeological remains with the *Macellum Liviae*, a shopping complex built by Augustus in the name of his wife Livia. Later studies have contradicted this affirmation and instead have stated that the remains are part of a *domus romana* that belonged to an important noble family. F. Guidobaldi (Steinby 1995) attributed the house to the *gens Nerati*, a powerful and recognized aristocratic family that participated actively in the political and economic life of the city from the centuries 1st AD to the 4th AD (Iannantuono 2010).

G. De Spirito (Steinby 1996) attributes the *domus* to *Flavius Anicius Auchenius Bassus*, a high official and consul of Rome from 425 to 435 AD. Liverani dates the remains to the Claudian or Neronian times (1st century AC) and argues that it is not possible to track the owner of the *domus* as the available information is not specific enough (Liverani 1987). Therefore, he clarifies that the Santa Maria Maggiore Basilica was built over the remains of two Roman houses. Of one of these houses there are very few archeological elements to evaluate its context; the second one, the one with the painted calendar, which he called Domus of the Calendar, is the case study chosen for this investigation.

3. Methodology and data acquisition

The integrated survey project of the architectural and archeological complex of the Basilica of Santa Maria Maggiore was carried out using active and passive terrestrial and aerial technologies. A data acquisition survey was performed using a 3D laser scanner integrated with photogrammetric data acquired from Structure from Motion (SfM) processes – photographic camera and drones for this purpose – and data obtained from the iPad LiDAR scanner. The laser scanner works by determining ranges of distances by targeting an object with a laser and measuring the time for the reflected light to return to the receiver. With this tool, the geometric features of the objects are extracted efficiently. The result of a laser scanner is a point cloud which is an array of points with spatial information of a very high accuracy (coordinates), and RGB information of low accuracy (color).

The SfM is a low-cost technique for estimating 3D information from a sequence of 2D images (photos). The results from this technique are point

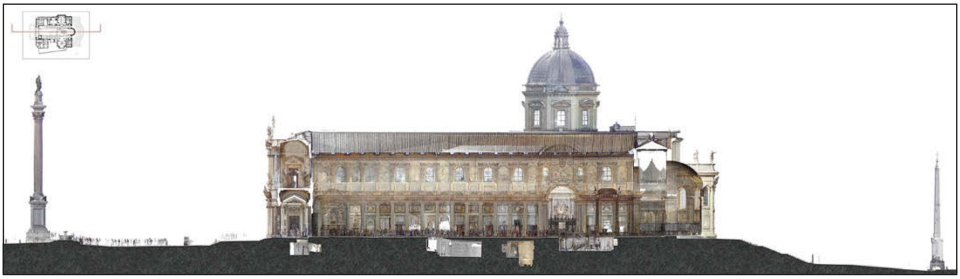

Fig. 3 – Longitudinal section-laser scanner point cloud.

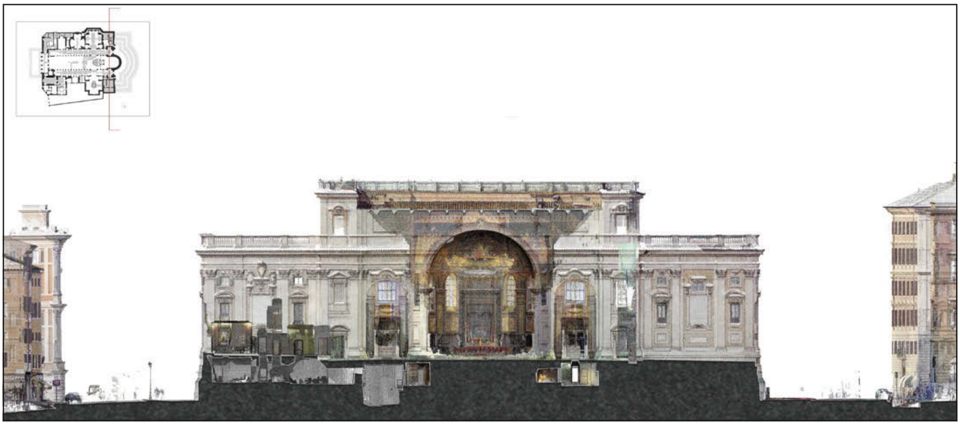

Fig. 4 – Cross section-laser scanner point cloud.

clouds with spatial information of low accuracy and RGB information of high accuracy. However, the accuracy of the spatial information can be increased by adding control points with known coordinates. The SfM also allows to easily generate 3D models with high-quality texture. The iPad LiDAR camera is also a low-cost instrument. It is a relatively new tool that has been adapted for data acquisition by the development of applications; it is also very versatile and allows the user to see in real time the information acquired. This is, perhaps, one of the first times a device of these characteristics is used in a data acquisition survey campaign with archaeological elements. The results of the comparison analysis from this tool can open the way to further investigations due to its innovative nature.

The whole complex was surveyed using a laser scanner. This instrument allows massive data acquisition of large-scale objects with accuracy and speed that would be difficult to achieve using any other instrument; it enables

Fig. 5 – Cross section-laser scanner point cloud.

two-dimensional restitutions with an accuracy of 1 mm on a 1:50 drawing scale. The SfM and the iPad LiDAR scanner were used to complement the laser scanner numerical data by providing higher chromatic information in a level of detail that cannot be achieved with the laser scanner; these technologies were used to survey only selected elements of high aesthetic and historic value. During the surveying campaign, to carry out the qualitative data comparison, four elements from the Domus of the Calendar were chosen. These are archaeological elements of exceptional value. The subjects were surveyed using laser scanners, a photographic camera (Canon EOS RP) and the iPad LiDAR camera (iPad Pro).

To photograph the selected archaeological elements – and given the limited dimensions of the rooms where these are exposed – a 24-105 f/4 mm lens was used, set at a focal length of 24 mm for the entire campaign. The archaeological site is illuminated with strong artificial lights; some of these are directed towards the archaeological remains, generating scenes of notable contrast which does not allow an adequate exposure for a photographic capture. This was addressed by using a controlled lighting system to illuminate only the archaeological elements in the dark. These dim conditions required increasing the exposure time to 10 seconds, so a tripod was necessary to achieve correctly exposed images. The photos were taken in RAW format for highest quality, then post-processed in an image manipulation software and finally exported in TIFF format. The resulting images were processed using the software AgisoftMetashape, which performs photogrammetric operations for the generation of 3D spatial data. Subsequently, filtering the acquired data removes unnecessary elements like the scattered points that do not represent the subject surfaces. The resulting point clouds are scaled to match the spatial data of the laser scanner. The scaling of the point cloud consists in assigning absolute dimensions to the reconstructed elements with relative dimensions.

This phase influences the results of the whole process of reconstruction and comparison; the level of accuracy in its execution unequivocally determines the metric reliability of the final model and the one from relative comparisons between models. By the mean value of three significant lengths selected on the laser scanner model, it was possible to determine the scaling parameter process. This approach is more reliable than comparing single points from the reference model. Decimated data allows effective manageability since the range approach (from the laser scanner) and image-based approach (from the SfM) generate models requiring computational costs that limit the hardware performance when processed. The data was then decimated to allow effective manageability, since in both the range approach (from the laser scanner) and image-based approach (from the SfM) the generated models require computational costs that limit the hardware performance when they are processed. The data obtained from the iPad LiDAR camera was registered using the app SiteScape, a versatile tool for scanning scale-accurate 3D spaces (https://www.sitescape.ai/). This data was not scaled as the LiDAR camera registers accurately the spatial characteristics of the scanned subjects.

For the data comparison, the three-dimensional mathematical models (point clouds) were processed in the software Cloud Compare (http://www.cloudcompare.org/). The SfM models and the iPad LiDAR camera models were aligned with the laser scanner model by using the ICP algorithm (Iterative Closest Point) that helps to minimize errors when aligning the models. This was followed by a spatial deviation comparison in two phases: comparing the laser scanner model with the SfM model and comparing the laser scanner model with the iPad LiDAR camera. This comparison aimed to quantify not only any deviation in terms of distance between the different models; but also other aspects that may affect the three-dimensional reconstruction process, such as costs, skills, time and computational costs, necessary elements to provide an optimized digital model (Figs. 3-5).

4. Results

For the comparison, four representative archaeological elements were selected from the Domus of the Calendar: an exedra (Room IV), a wall with marble incrustations (Room VIII), a mosaic (Room IX) and a portion of the calendar fresco (Room X) (Fig. 6). The results are shown according to the level of complexity of each element, in the following order: 1) mosaic, 2) calendar fresco, 3) wall with marble incrustations, and 4) exedra.The results

Fig. 6 – The photos of four different parts of the four rooms of the the Domus of the Calendar (SfM).

		Points Obtained		
Room	N° Photos (SfM)	Laser scanner	SfM	iPad LiDAR camera
IV (Exedra)	296	10.292.585	93.368.698	878.279
VII (Marble incrustations)	94	1.973.992	2.356.994	437.494
IX (Mosaic)	75	1.268.523	3.536.238	231.374
X (Calendar Fresco)	182	2.704.068	2.992.706	621.209

Tab. 1 – The Point cloud comparison analysis.

are registered in an RGB color scale: blue indicates a minimal variation (0 cm) in comparison to the reference data, green is a medium one (1 cm), while red represents a high one (> 2 cm). The scaled values on Figs. 7, 8, 9, and 10 are represented in meters. The input data for this analysis is shown in Tab. 1.

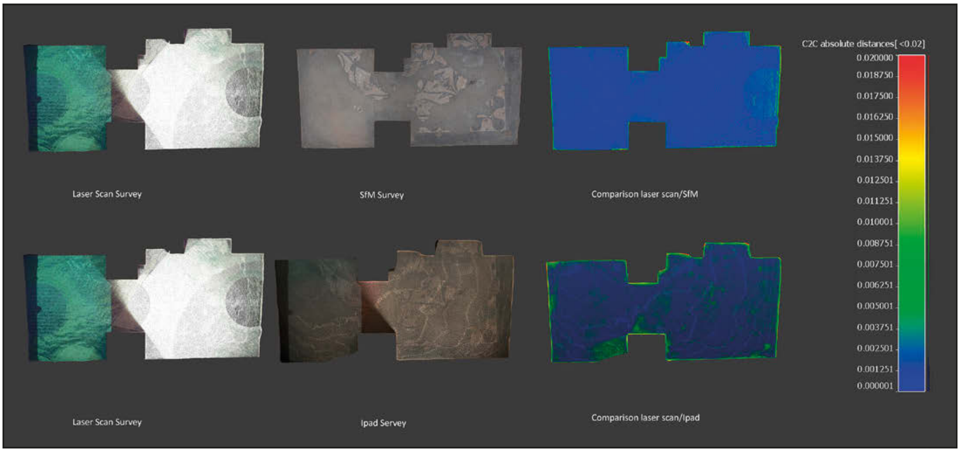

Fig. 7 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room IX, mosaic.

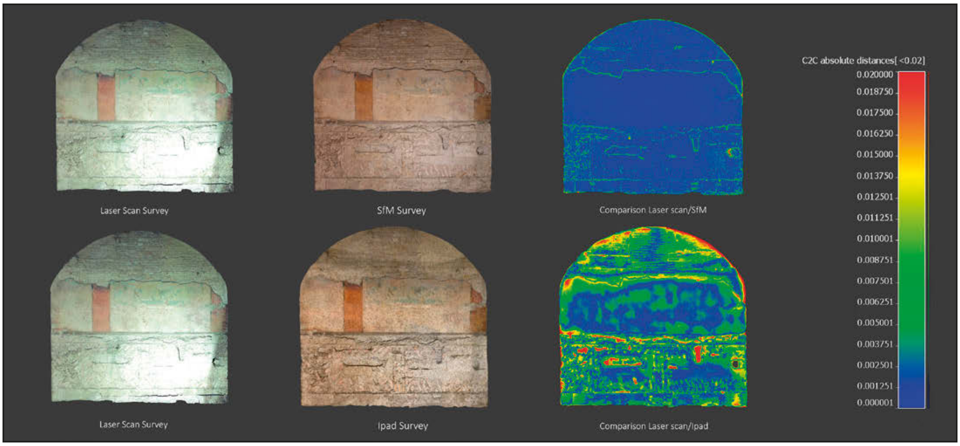

Fig. 8 – The comparison between different survey methodologies (SFM, laser scanner, iPad): Room X, Calendar fresco.

4.1 *Results: laser scanner vs SfM*

The results from this comparison show that the data acquired with the SfM methodology has minimal variations from the data obtained with the laser scanner. Thus, it can represent reality with high accuracy. In the mosaic and the fresco, for example, there is practically no variation between both survey methodologies, as both results appear in blue (Figs. 7, 8). There are

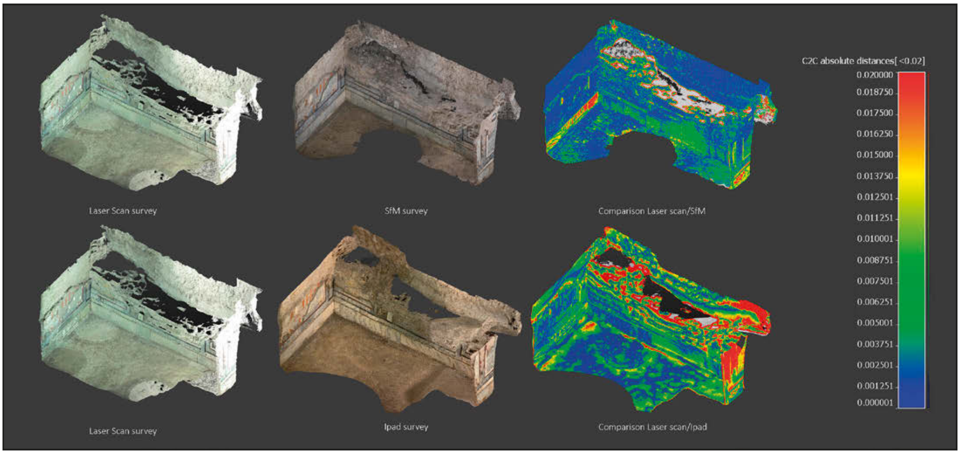

Fig. 9 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room VIII, marble incrustations.

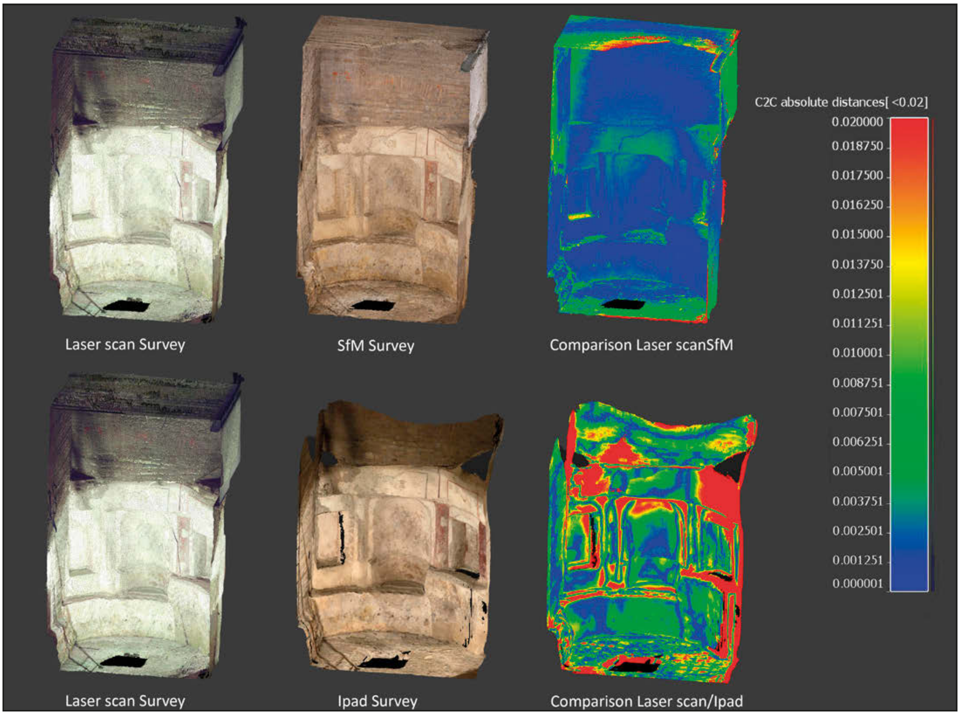

Fig. 10 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room IV, exedra.

some instances in which the data from the SfM have noises. This noise is registered with a red color on the results from the marble incrustations and the exedra (Figs. 9, 10). This implies that there is a significant variation compared to the reference data. Significant data variations are also present in irregular surfaces. This can be seen in the results in green from the comparison of the wall with marble incrustations (Fig. 9). Elements with complex geometry seem to be well represented by the SfM, especially if the surfaces of the element are regular. This evidence is shown in the results from the exedra, where almost all the information is coloured in blue (Fig. 10).

4.2 *Results: laser scanner vs iPad LiDAR camera*

The results from the iPad LiDAR camera have shown significant variations compared to the laser scanner data. Firstly, it represents good elements with simple geometry, as can be seen from the results of the mosaic with a predominance of the blue color (Fig. 7). When there are minimal protrusions on the surface of the elements, the results vary considerably from the ones obtained with a laser scanner. To be seen comparing the wall fresco of the calendar (Fig. 8) and the wall with marble incrustations (Fig. 9), where there is a high amount of information in green and red colors. In elements with complex geometry, such as the exedra, the iPad VR faces difficulties logging spatial properties; therefore, sizeable portions of the results are in green and red colors (Fig. 10).

5. Discussion

The comparison between the data acquired highlighted the potential of the photogrammetric approach, integrated with the SfM methods, and the iPad LiDAR camera, to collect reliable three-dimensional data on an architectural scale. In the operational phase, the difficulties due to any unforeseen relevant conditions can lead sometimes to gaps or inconsistencies in the data returned. This can also result in processing redundant data, with consequent data-management difficulties. Therefore, it is necessary to conduct a preliminary evaluation of the elements to establish the number of shots required for its registration; this can vary depending on the camera lens and the distance from the object. The iPad LiDAR camera, even if user friendly requires having good expertise as it might be necessary to repeat the data acquisition process to obtain a surveyed area without overlapping surfaces.

The laser scanners ensured greater reliability from an operational point of view, with obvious advantages both during the survey and data processing phases. The only limitation was the impossibility of scanning from different heights, and not having a scaffolding arrangement. From the data quality point of view, there is an obvious difference when comparing the results from an architectural and archaeological perspective. In the SfM, the object of study provides high-quality textured results compared to the model obtained from the laser scanner. The iPad LiDAR camera constructs a digital copy of the surveyed object, from which it is possible to obtain metric information with a satisfactory quality and an aesthetically approved result. However, the laser scanner is the methodology that best represents reality from a metric point of view.

6. Conclusions

The data acquisition survey project carried out on the Domus of the Calendar compared different survey methodologies: laser scanner, SfM and the iPad LiDAR camera. It consented to evaluate the qualitative level of data that can be reached by photogrammetric systems and portable devices, applied in a multi-scalar complicated archaeological context. The SfM has proven to be a reliable tool for representing the geometry of simple and complex elements. Due to its high accuracy, it can be used for representing elements that require a high quality of data, such as small archaeological objects. The iPad LiDAR is a tool that represents accurately the spatial information of elements of simple geometry. It can obtain the geometry of objects and spaces with relatively good precision. However, its use is not advisable in projects that require high-precision data. Its use is only advisable for representing volumes and shapes of archaeological and architectural objects that do not require a high level of precision.

The data acquisition comparison analysis shows that low-cost technologies like the SfM and the iPad LiDAR are reliable tools for representing physical space. Portable devices, due to their early stage of research and development, need to be improved to obtain a more precise and accurate representation of space. In the future, they will probably redefine the survey data acquisition process using digital tools, due to their versatility, intuitive use and information accessibility, as they provide the results almost instantaneously. These characteristics are in contrast with the SfM and the laser scanner, as they require a good level of expertise to be handled and long amount of time to process the information.

The possibility of producing different graphic restitution from the same three-dimensional models allows the conduct of analysis with data of different complexities. It was possible to correlate several phenomena that represent the entire architectural complex for different purposes: for example, as a diagnosis tool for planning potential restoring interventions.

The laser scanner is the only instrument that provides a reliable metric, geometric and morphological representation of a large complex like the Basilica of Santa Maria Maggiore. Smaller scale areas and objects can be chromatically and morphologically controlled using SfM and the iPad LiDAR. According to our research, the laser scanner gives the most accurate representation of a real object. In the comparison between the SfM and the iPad LiDAR, the SfM is the tool with the least uncertainty concerning to the numerical model acquired with the laser scanner.

Alfonso Ippolito, Claudia Palmadessa, Mahsa Nousrati Kordkandi
Department of History, Design and Architecture Restoration
Sapienza University of Rome
alfonso.ippolito@uniroma1.it, claudia.palmadessa@uniroma1.it
mahsa.nousratikordkandi@uniroma1.it

Juan Camilo Arias Tapiero
Department of Civil Engineering
Institute for Sustainability and Innovation in Structural Engineering (ISISE)
University of Minho
id10058@alunos.uminho.pt

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ABSTRACT

Data acquisition digital methodologies have become a reliable tool for surveying buildings with heritage values. Laser scanning has become the preferred method for performing 3D digital surveys because of its high accurate results; even though, the cost associated with it is usually high. Emerging technologies have been able to produce low-cost data acquisition methods, and they are currently being incorporated as part of digital survey projects. Using the Domus of the Calendar as a case study – an exceptionally unique archaeological and architectural site that was incorporated to the structural foundation system of the basilica of Santa Maria Maggiore – the present investigation aims to evaluate the data quality of two low-cost emerging technologies, namely SfM (Structure from Motion) and the iPad LiDAR system. This evaluation was developed by comparing low-cost technologies data acquisition capabilities with those of the laser scanner. The data for this test was obtained during an integrated survey campaign aimed at executing a critical analysis of the many historical layers of the Santa Maria Maggiore basilica. The results obtained from this investigation highlights the reliability of the different techniques implemented and suggest a useful solution for different and recurrent multi-scalar contexts.

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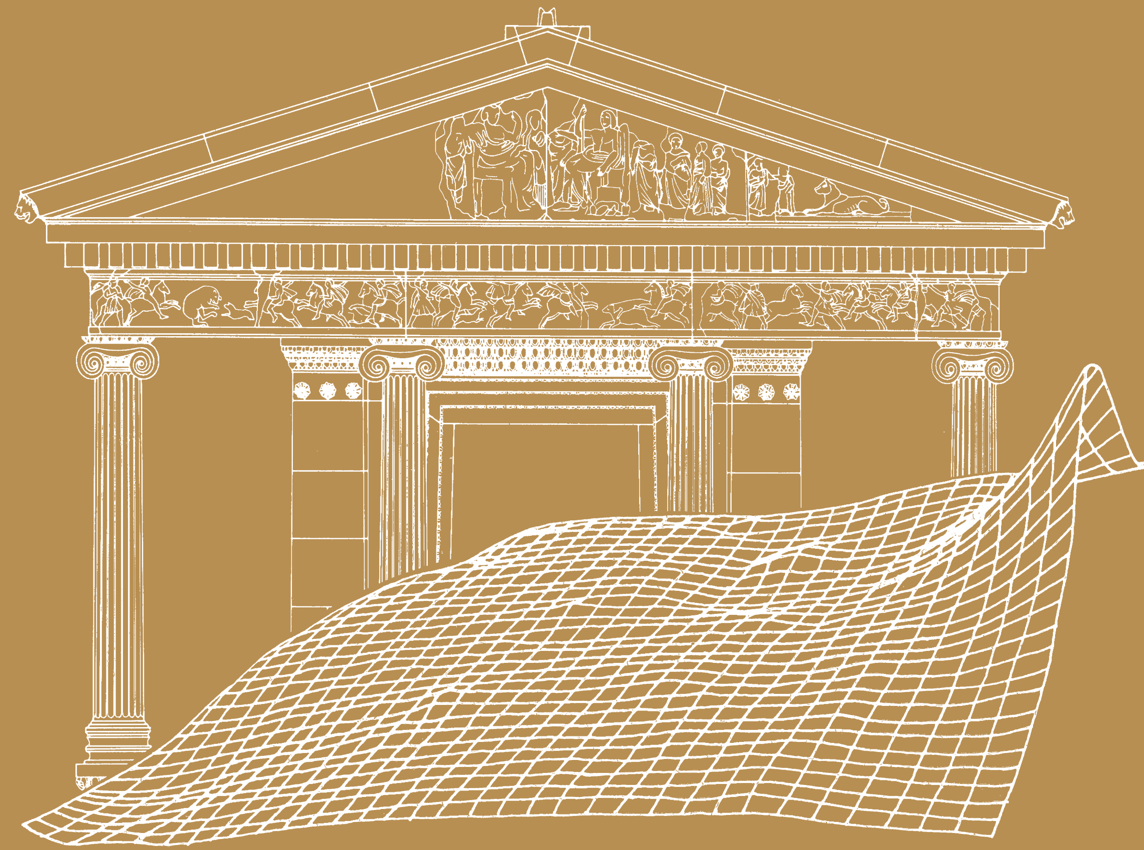

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