The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-1/W5-2025
13th International Conference on Mobile Mapping Technology (MMT 2025)
"Mobile Mapping for Autonomous Systems and Spatial Intelligence", 20–22 June 2025, Xiamen, China

Fast survey methods and tools for historical city center: a review

Silvia La Placa[1]

[1] DICAr_Department of Civil Engineering and Architecture, University of Pavia, 27100, Pavia, Italy, silvia.laplaca@unipv.it

Abstract

This paper presents a critical review of fast survey methods and tools applied to the documentation of historical city centers, with a focus on Pavia. Within the framework of the DORIAN project, which aims to create a Digital Twin of the city, the research evaluates different Mobile Laser Scanner (MLS) and SLAM-based technologies, along with kinematic terrestrial laser scanners, to achieve metric accuracy in reduced acquisition times. The experimentation was conducted on the Cairoli University College and its adjoining square, providing diverse conditions for testing both indoor and outdoor environments. The study demonstrates the potential of these methods to support the conservation and valorization of architectural heritage while enabling sustainable urban planning. Ultimately, the developed 3D database represents the foundation for the future Digital Twin of Pavia's historical city center, serving as an interoperable infrastructure for research, management, and resilience strategies.

Keywords: Fast survey, Mobile Laser Scanner, metric accuracy, 3D database, Historical city center, Pavia.

1. Introduction

This contribution deals with the topic of the fast survey of valuable architecture and public spaces in historical urban centres, for the construction of metrically reliable digital duplicates. The analysis focuses on some of the most up-to-date tools (hardware and software) for expeditious surveying, through the comparison of application methodologies of data acquisition and processing and of results obtained with different tools on the same case study (Di Stefano, et. Al., 2021). The review aims to critically summaries advantages and disadvantages of tested processes and technologies, providing a table of values to facilitate the choice of methods in future applications. The experimentation activities conducted are part of the 2023-27 Department of Excellence Project 'DORIAN Digital modelling to support the design of safe, sustainable and resilient Environments' of the DICAr_Department of Civil Engineering and Architecture of the UNIPV_University of Pavia, Italy. Exploiting the multidisciplinary nature of the Department, DORIAN develops reflections and research on the relationship between 'real' and corresponding digital simulation. The project defines an unique methodology aimed at the development of a Digital Twin of the Pavia historical centre, serving the territory and industry and in the perspective of sustainability, resilience and safety of the 2030 Agenda.

To obtain the digital twin, first a metrically reliable 3D database of the city must be developed in reduced time. To this purpose, project Action 1 is dedicated: 'The enabling infrastructure: GIS3D database', for the acquisition of Lidar (Light Detection and Ranging) data from aircraft and SLAM (Simultaneous Localization and Mapping) data from the ground, for selected areas of the historic centre of Pavia.

This activity should provide a GIS3D database, to be verified, validated and made available to the other working groups, which will use the infrastructure as a basis for subsequent activities. Infact, this database is the basis for the construction of management and forecasting models for the territory (Parrinello, Picchio, 2023).

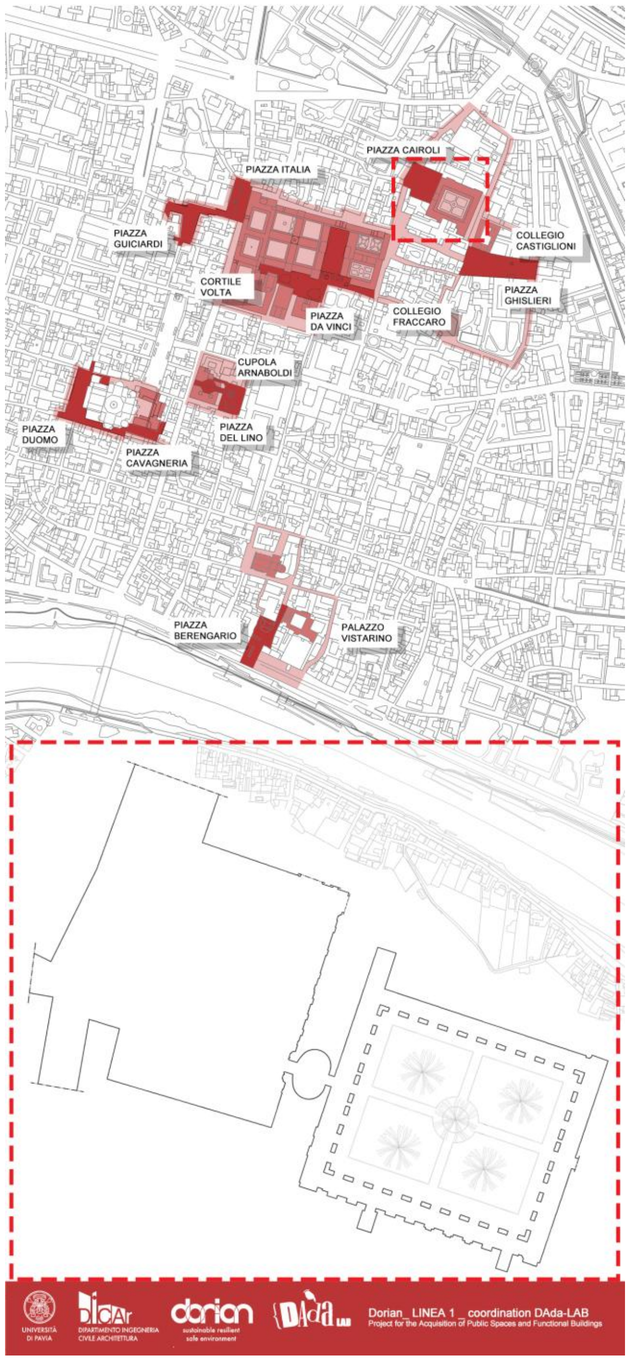

Figure 1.
On the right, the historic center of Pavia, where the main squares and buildings studied by the DORIAN Project have been highlighted. Below, focus on Piazza Cairoli and the historic building of the College. Author's elaboration.

Hence the need to carry out numerous tests and experiments of fast acquisition on the same significant case study. Comparisons on the latter allow: to establish, in relation to diversified parameters (acquisition timing, colorimetric accuracy, instrument flexibility of use, etc.), the most appropriate fast survey methods and the most suitable technologies to achieve the set results; and to define their applicability on the diversified types of built heritage within the urban fabric.

2. Case study

As part of the DORIAN Project, the entire historic centre of Pavia will be documented, with a focus on the main squares and public spaces. To begin with, the case study of the Cairoli University College (main façade and internal garden) and the contiguous square in the Pavia historical centre was chosen for experimentation. This choice made it possible to evaluate the methods and tools effectiveness in both open urban spaces and closed courtyards. The building, dating back to the 14th century, was originally a monastery.
Over the centuries it changed use several times, until it became a University College in 1948. The dynamism of the façade, with its numerous mouldings, and the decorative richness of the portico in the inner garden are optimal details for assessing the point clouds accuracy and precision. At the same time, the square different inclinations in front of it provide a further opportunity for verification: the more faithful the reconstruction of the Digital Terrain Model, the better the working basis for subsequent redevelopment and/or design work on an urban scale (Angelini, et. Al., 2023; Guan, et. Al., 2016).

Figure 2.
Piazza Cairoli, now used as a public parking lot. On the right, the main facade of the Cairoli College. Photo by the author.

3. Experimentation of methods and tools

In particular, this contribution will discuss the experiments and methods applied for SLAM data acquisition, within Action1.
In recent years, mobile 3D surveying from the ground has developed various types of portable solutions for close-range mapping: innovative hardware and software systems are designed to meet the need for rapid surveying and the production of increasingly high-performance data that can be easily associated with reality-based modelling operations.These models are used in the construction sector in various fields of application from architectural surveying to civil engineering, territorial analysis, and the enhancement and conservation of cultural heritage. All these fields are now, in the fast progression of the digital age, closely connected to the experimentation of innovative processes of documentation, management and use of knowledge. The development of algorithms and sensors, optimised for digital surveying and the use of the most up-to-date technologies for rapid survey in motion make it possible to develop new categories and acquisition protocols for the production of models that can be used as tools for specialised knowledge or for the dissemination and preservation of the historical memory of heritage.

Figure 3.
Composition from point clouds obtained with different applied technologies. From above: overview of Piazza Cairoli and the inner courtyard of the University College; Cairoli University College, main façade and inner garden. Author's elaboration.

It is from these premises that the collaborations, initiated by the DAda-LAB & PLAY Laboratories of the Department of Civil Engineering and Architecture of the University of Pavia, with numerous companies operating in the field of surveying and documentation originate. The synergic relationship between researchers and professionals has made it possible to conduct instrumental experiments (from the use in the field, to the processing and optimisation of scanning source data, to their comparison and validation) aimed at obtaining extensive survey systems that are as geometrically accurate and complete as possible in an absolutely short time. The agreements stipulated with these companies have made it possible, over the years, to test some of the most up-to-date MLS_Mobile Laser Scanner technologies (Dell'Amico, La Placa, 2024). In the case of the DORIAN Project, acquisitions (and subsequent comparisons) were conducted with five different technologies.

3.1 MLS Acquisition: Blk2GO Leica

Leica's Blk2GO, with GrandSLAM technology, uses real-time LIDAR scanning and SLAM tracking for 3D mapping. It has 3 panoramic and one 12 MP front-facing camera and is equipped with an IMU_Inertial Measurement Unit to calculate position change during operator movement. Designed for indoor acquisitions (max. range 25 m), its use has been tested in urban contexts characterised by particularly dense fabric, with effective results (Dell'Amico, 2023). The Blk2Go tool, for which there is also a short 'guide for dummies' produced by the DAda-LAB and PLAY Laboratories, was developed for the fast documentation of large buildings and with a useful result, in terms of the type of data, for constructing the basis of BIM projects (Dell'Amico, et al., 2023) and/or CAD drawings. To reduce the drift error, it is optimal to follow an acquisition methodology for closed circuits. The scans produced are optimised (in visualisation but also in registration) when processed on the proprietary Leica Cyclone REGISTER 360 PLUS and Cyclone REGISTER 360 PLUS (BLK Edition) software.

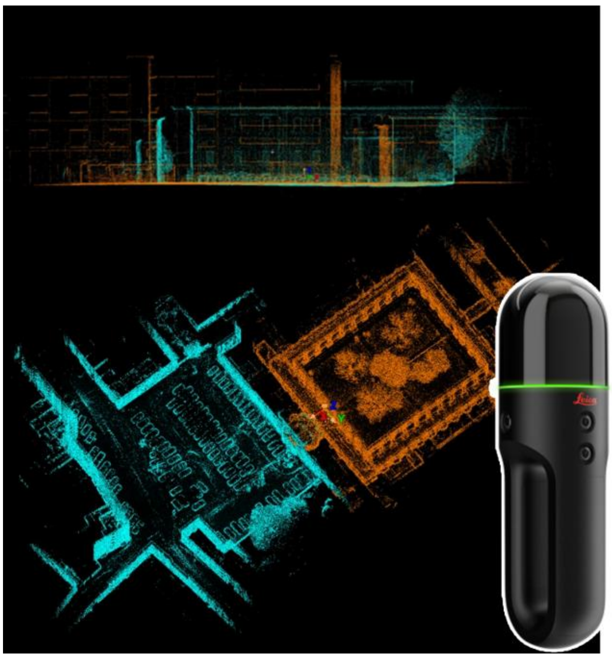

Figure 4.
Alignment and registration of two scanning paths (in blue: Piazza Cairoli, in orange: the College courtyard) carried out with Leica Blk2GO equipment. Author's elaboration.

3.2 MLS Acquisition: Pegasus TRK Leica

Leica's Pegasus Trk 500 neo, with TRK technology, is a car-mounted mobile mapping system. Equipped with 24 MP front and panorama cameras, it captures 500,000 measurements per second (max. range 490 m) and is designed for surveying roads and infrastructure.

As an instrument designed for large-scale acquisitions, Leica has developed special software "Leica Pegasus FIELD" to make data collection autonomous. Through FIELD, the operator can plan routes in advance or in the field as required. In addition, thanks to edge computing and on-the-fly processing, data is collected and improved in real time. Added to this is the "Leica Cyclone Pegasus OFFICE" software, which refines the data through georeferencing and multi-pass trajectory adjustment and generates 3D point cloud data with a colorimetric component (Treccani, et al., 2024).

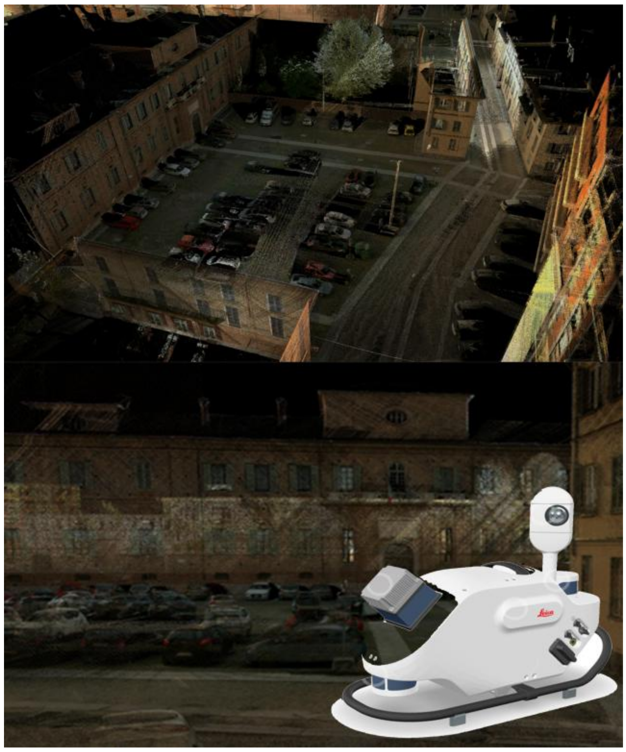

Figure 5.
Colorized point cloud obtained from a single pass of the Leica Pegasus TRK instrument, vehicle-mounted. Author's elaboration.

3.3 MLS Acquisition: Heron MS TWIN Color Gexcel

The HERON MS TWIN Color model is equipped with a dual 32-channel LiDAR sensor and a four-lens 360° RGB 8K camera. The system (max. range of 300 m) is characterised by great versatility of use (acquisition head can be attached to telescopic poles) and can therefore be used for outdoor and indoor documentation, even in inaccessible conditions for the operator, including dark or restricted spaces (such as basements or attics). The technology is designed for geospatial applications and Digital Twin construction. The acquisition data, which can be integrated with drone and camera data, can be processed using the proprietary RECONSTRUCTOR software. The software features a patented SLAM algorithm, time bars to organise customised processing and filtering of moving objects, and is designed to allow the construction of mesh models and calculations of volumes, areas, profiles and contours (Vassena, Sgrenzaroli, 2023). Being to all intents and purposes a technology rather than a tool, advancements and updates are constant.

3.4 MLS Acquisition: VLX 2 NavVis

The VLX 2 is a portable system that acquires 3D measurements with two 16-layer lidar sensors in combination with SLAM software.
The instrument is equipped to acquire control points in a global or local co-ordinate system, equipped with 4 panoramic cameras and an integrated touchscreen interface. Designed to be worn by the operator, it can acquire indoor and outdoor spaces (max. range 100 m). NavVis technology allows georeferencing points during acquisition by rotating the instrument and positioning it on the point of interest (horizontal or vertical). Acquisitions are processed in the cloud, which allows it to operate with any type of computer (the weight of the cloud does not burden the disk), as long as it is connected to an internet network (Askar, et al., 2023).

Figure 6.
Point cloud of the main facade of the Cairoli College and the internal courtyard, acquired with the Gexcel Heron MS TWIN Color instrument. Author's elaboration.

3.5 TLS Acquisition (kinematic version): Riegl VZ-600i Microgeo

The Riegl Serive V-Line scanner acquires measurements with an accuracy of 3 mm (max. range 1000 m) and is equipped with a vegetation overrun system. It allows automatic registration and georeferencing without external devices and is equipped with 3 integrated cameras.
Among the advantages of this technology is the possibility of associating the instrument head (already equipped with internal cameras) with a 360° camera, to obtain high-resolution pano images, or with a GNSS RTK system to obtain all the information related to position and altitude according to global coordinates (Pöppl, et al., 2023). Although it is a static instrument, a single scan, including the acquisition of colour images, has a minimum duration of just 30 seconds (times increase depending on the configured settings).

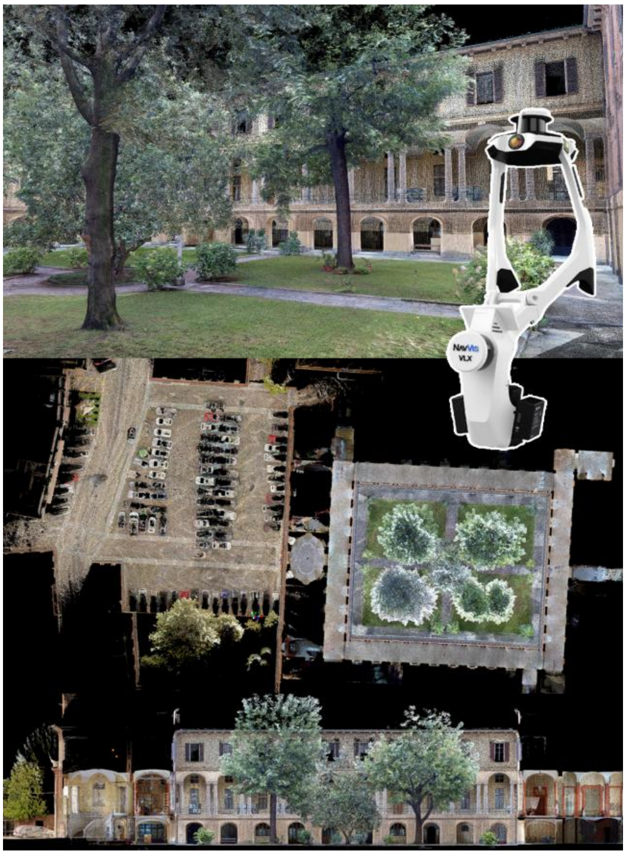

Figure 7.
Views of the point cloud of Piazza and Cairoli College, acquired with the NavVis VLX 2 instrument. Author's elaboration.

Still in the context of reducing survey times, the tool also allows scanning of scans on board the machine and simultaneously makes the alignment status viewable from the smartphone. However, there is also the possibility of using the instrument in kinematic mode: it can be mounted on a special stand or on a rigid backpack equipped with a pole, or even used on a car, boat or hand truck).
The point cloud produced in kinematic mode maintains a high density, thanks to the possibility of setting all the acquisition characteristics in detail, but lacks photographic data.

4. Instruments and database comparison

At the conclusion of the data acquisition campaigns, a set of comparative parameters was established to identify the most suitable hardware and software tools—and consequently, the resulting database—for meeting the requirements of fast surveying and for generating a three-dimensional base model to support the production of a digital twin of a historic city center. In particular, the following criteria were considered:

- Instrument portability: this includes the weight of the equipment, which must be manually transported due to the inaccessibility of many squares by vehicle, as well as its operational flexibility. The ability to maneuver in narrow spaces and over irregular paving surfaces—such as cobblestones and stone-set pavements, which are poorly suited for wheeled transport—was a critical factor;
- Customizability of the acquisition process: this refers to the capacity to manually define appropriate settings and adjust them in real time in response to changes in the environment.

https://doi.org/10.5194/isprs-archives-XLVIII-1-W5-2025-45-2025 |

Such adaptability by the operator—especially when transitioning between areas of varying light conditions (e.g., from bright to shaded zones), from indoor to outdoor spaces, or between large open squares and narrow, elongated alleys—can significantly enhance the scanning process and help minimize acquisition error;

Figure 8.
Views of the point cloud in true color (obtained from static scans) and reflectance (obtained from kinematic survey) of the case study. Author's elaboration.

- Acquisition speed: this parameter was particularly relevant due to the need to deliver a database that was both as complete and as metrically accurate as possible within a limited timeframe, in order to enable subsequent phases of the project by other research groups;
- Acquisition range: a higher range allows for the collection of a greater quantity of data within the same time frame. This, combined with acquisition speed, plays a crucial role in meeting the project's requirements;
- Data processing flexibility: the openness and adaptability of the software platform were key considerations. The ability to monitor and adjust parameters during various stages of elaboration.

For urban reconstruction purposes, the Pegasus TRK system offers clear advantages in terms of acquisition speed—being vehicle-mounted—and point cloud density, which remains highly performant despite the dynamic conditions of data collection. However, given that historic Italian city centers are often characterized by very narrow alleys, restricted traffic zones, and environments such as internal courtyards (a prominent feature of the urban fabric of Pavia) accessible only on foot, achieving a comprehensive database requires integrating Pegasus data with data acquired using other instruments. Versatility and flexibility of use are key features of both the BLK2GO and the Heron MS TWIN Color systems. The former provides excellent results indoors and in enclosed environments, making it particularly suitable for acquiring data in historical courtyards. The latter—wearable as a backpack or mounted on a pole—is ideal for surveying narrow or hard-to-access spaces. Its technology allows the operator to monitor the acquisition path in real time and make targeted adjustments to the alignment of different trajectories, thereby ensuring high reliability of the final result.

The NavVis system represents a next-generation mobile mapping platform that delivers high-density point clouds with finely calibrated camera systems. The quality of the colorized point cloud facilitates the interpretation of architectural details by the operator, effectively supporting the creation of high-detail digital twins. Cloud-based data management does not pose significant challenges in urban environments where internet connectivity is available.

Finally, the Riegl technology offers onboard scan registration, significantly reducing the time required to generate point clouds, while also allowing post-processing adjustments for improved alignment validation. Although kinematic operation yields dense point clouds, it does not capture color information, thus necessitating integration with photogrammetric techniques or strategically placed static scans (typically requiring less than a minute per scan). The ability to mount the instrument's head on different mobile platforms further enhances its versatility for acquiring both streetscapes and enclosed environments.

5. Impact

The experimentation carried out as part of Action 1 of the DORIAN project has generated significant impact on both scientific and operational levels, opening new perspectives in the digital modeling of historic city centers and the development of interoperable metric infrastructures (Parrinello, et al., 2020).

The direct comparison of SLAM-based technologies in a real urban context allowed for the validation of rapid, flexible, and high-precision solutions, highlighting strengths and limitations according to various urban morphologies and application requirements. A concrete first result was the creation of a metrically reliable 3D database, intended to serve as the digital foundation for multidisciplinary studies on the city of Pavia. This infrastructure not only supports the conservation and valorization of architectural heritage, but also fosters collaboration between public institutions, academia, and industry, through the sharing of standardized geospatial data integrated within a GIS3D environment (Parrinello, et al, 2024).

Instrument	Typology	Weight dimension	Max measuring range	Range Accuracy	acquisition time/autonomy
Leica Blk2GO	MLS (handheld)	850 gr	25 m	10 mm	45 min
Leica Pegasus TRK	MLS (vehicle-mounted)	18 kg	450 m	12 mm	7 h
Heron MS TWIN Color	MLS (wearable/pole)	3 kg	120 m	4 mm	1,15 h
NavVis VLX 2	MLS (wearable)	8,5 kg	100 m	5 mm	1,5 h
Riegl VZ-600i	TLS (usable in kinematic version)	6 kg	1000 m	5 mm	1,5 h

Table 1.
Comparison of the instruments used according to the parameters defined by the research requirements.

Such an approach facilitates maintenance planning, sustainable urban development, and the implementation of climate resilience strategies—key themes within the framework of current European urban agendas.

At the methodological level, the tested approach contributes to overcoming the traditional dichotomy between accuracy and speed, often perceived as mutually exclusive in surveying practices. The analyzed technologies have demonstrated, to varying extents, the capacity to ensure rapid acquisitions without compromising data quality, making them particularly suitable for complex urban contexts subject to logistical, regulatory, and temporal constraints. Moreover, the comparative analysis resulted in an evaluation matrix that supports the informed selection of tools, contributing to the definition of replicable protocols in other historic environments.

From a cultural and educational standpoint, the project has had an impact by involving students, researchers, and professionals in field activities and critical analysis of results. This has promoted the dissemination of cross-disciplinary skills and the adoption of digital paradigms in architectural and urban surveying, reinforcing the synergy between technological innovation and historical knowledge.

Finally, the digital infrastructure developed during the project represents a strategic component for the future realization of a Digital Twin of Pavia’s historical center. This digital twin not only faithfully reproduces the city’s morphology, but will also be capable of integrating environmental, structural, and management data over time, evolving into a dynamic system that supports predictive simulations, intervention scenarios, and participatory decision-making processes.

6. Conclusions and Future Developments

This comparative analysis was made possible thanks to the strong synergy between academic researchers and industry professionals specializing in geomatics and 3D survey technologies. The collaborative framework fostered a rich exchange of knowledge, allowed for access to cutting-edge instruments, and enabled field testing under real operational conditions—ensuring a critical and practice-oriented evaluation of each system.

The comparative study conducted within the DORIAN project offers valuable insights into the effectiveness and limitations of various fast survey technologies for the metric documentation of complex urban environments. The diverse set of tested tools—ranging from handheld to vehicle-mounted and wearable SLAM-based systems, as well as kinematic terrestrial laser scanners—provided complementary strengths in terms of acquisition speed, data resolution, color information, and environmental adaptability. The experimentation demonstrated that no single device can address all challenges inherent to the documentation of historical city centers; instead, their integrated use and critical evaluation allow for a more nuanced and context-sensitive approach.

One of the most significant outcomes of this work is the creation of a robust and multi-source 3D database that forms the backbone for the future development of an Urban Digital Twin of Pavia. This database does not represent a static archive, but a dynamic, evolvable infrastructure capable of integrating heterogeneous datasets, from metric survey data to thematic GIS layers, environmental monitoring inputs, and heritage documentation. The comparative analysis performed in this study is instrumental in optimizing this infrastructure, as it provides a reference framework to identify which technologies are best suited to specific urban morphologies, spatial constraints, and data requirements.

By strategically combining datasets from different tools—each contributing unique advantages such as real-time path tracking, high-fidelity colorization, or long-range accuracy—it becomes possible to construct a Digital Twin that balances precision, scalability, and interoperability. Such a system can support diverse applications: from structural health monitoring and heritage management to urban planning, mobility simulation, and climate adaptation strategies.

Looking forward, the next steps will involve the integration of semantic data, enabling enriched interpretations of architectural elements, land use, and historical evolution. Furthermore, the implementation of time-based layers will allow the Digital Twin to evolve into a 4D platform, supporting simulations, predictive analytics, and decision-making processes aligned with smart city frameworks (Ricart, et al., 2022).

The replicability of this methodology in other historic urban areas makes it a promising model for sustainable digital transformation in the heritage sector. Through continued interdisciplinary collaboration, the Pavia case study thus stands as a benchmark for future urban-scale digital twin initiatives.

Figure 9.
Comparison of point clouds of the same case study: the entrance portal of Collegio Cairoli in Pavia. Author's processing.

Acknowledgements

The research work is partially supported by the MUR (Ministry of University and Research) program "Departments of Excellence 2023–2027", within the project "DORIAN of DICAr - Digital modeling in support of the design of safe, sustainable and resilient environments". In particular, some results of the actions conducted by the Experimental Teaching and Research Laboratory DAda-LAB of DICAr are presented here, within Line 1 "The enabling infrastructure: GIS3D database".

References

Angelini, R., Luzi, G., Ribas Prats, F., Masiero, A., & Mugnai, F. (2023). A review and test of shoreline extraction techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*(1/W1-2023), 17-24.

Askar, C., Scheider, A., & Sternberg, H. (2023). Evaluation of a State-of-the-Art Indoor Mobile Mapping System in a Complex Indoor Environment. *ZfV-Zeitschrift für Geodäsie, Geoinformation und Landmanagement*, (zfv 5/2023).

Dell'Amico, A. (2023). Scan to H-BIM, drawing information and model sharing protocols. The case study of the Castiglioni Brugnatelli college (PV). In *Digital & Documentation vol. 4* (Vol. 4, pp. 72-87). Pavia University Press.

Dell'Amico, A., Sanseverino, A., & Albertario, S. (2023). Point Cloud Data Semantization for Parametric Scan-to-HBIM Modeling Procedures. In *Beyond Digital Representation: Advanced Experiences in AR and AI for Cultural Heritage and Innovative Design* (pp. 515-533). Cham: Springer Nature Switzerland.

Dell'Amico, A., & La Placa, S. (2024). La documentación digital del centro histórico de Santa Cruz de Mompox, declarado Patrimonio de la Humanidad por la UNESCO. *Mimesis, Journal of Science of Architectural*, *4*(4), 41-48.

Di Stefano, F., Torresani, A., Farella, E. M., Pierdicca, R., Menna, F., & Remondino, F. (2021). 3D surveying of underground built heritage: Opportunities and challenges of mobile technologies. *Sustainability*, *13*(23), 13289.

Guan, H., Li, J., Cao, S., & Yu, Y. (2016). Use of mobile LiDAR in road information inventory: a review. *International Journal of Image and Data Fusion*, *7*(3), 219–242. https://doi.org/10.1080/19479832.2016.1188860

Parrinello, S., De Marco, R., & Galasso, F. (2020). Un protocollo di modellazione urbana mediante abachi e modulo tecnologici. Dal rilievo digitale al sistema informativo 3D per il centro storico di Betlemme. *DN*, *6*, 52-69.

Parrinello, S., & Picchio, F. (2023). Digital strategies to enhance cultural heritage routes: from integrated survey to digital twins of different European architectural scenarios. *Drones*, *7*(9), 576.

Parrinello, S., Picchio, F., & La Placa, S. (2024). The Construction of an Informative 3D Model for the Monitoring of City Heritage Risk. In *Reviving Aleppo: Urban, Legal and Digital Approaches for Post-War Recovery* (pp. 243-274). Cham: Springer International Publishing.

Pöppl, F., Pfennigbauer, M., Ullrich, A., and Pfeifer, N., "Trajectory estimation with GNSS, IMU, and LiDAR for terrestrial/kinematic laser scanning", Proc. SPIE 12537, Laser Radar Technology and Applications XXVIII, 1253706 (12 June 2023); https://doi.org/10.1117/12.2663454

Ricart, S., Berizzi, C., Saurí, D., & Terlicher, G. N. (2022). The Social, Political, and Environmental Dimensions in Designing Urban Public Space from a Water Management Perspective: Testing European Experiences. Land, 11(9), 1575. https://doi.org/10.3390/land11091575

Treccani, D., Adami, A., Brunelli, V., & Fregonese, L. (2024). Mobile mapping system for historic built heritage and GIS integration: a challenging case study. *Applied Geomatics*, *16*(1), 293-312.

Vassena, G. P., & Sgrenzaroli, M. (2023). Innovative and efficient data census on a cloud based digital twin provided by mobile mapping. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*, 531-537.