TOWARDS INTEGRATED APPROACHES TO DIGITAL DOCUMENTATION OF RAILWAY INFRASTRUCTURE IN THE URBAN ENVIRONMENT

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ABSTRACT:

Digital documentation of the built environment and its transformations is increasingly emerging as a strategic tool for achieving sustainability, energy saving and effective decision-making processes. To address the complexity brought on by the phenomena of territorial and urban modification, an integrated approach to digitization in support of intervention processes on the existing heritage does appear to be a feasible option. The actors in the supply chain are being driven toward the use of multiple technologies and integrated information systems by the need to integrate information sources of various kinds, to enable the multi-scalar verification of intervention scenarios –past, present, and future– as well as to correlate the project alternatives to the occasionally involved citizens' unique needs.
This contribution details the main outcomes of the management of urban railway networks' transformation using integrated digital technologies. In cooperation with the third-largest manager of the nation's rail system, integrated three-dimensional terrestrial survey, drone, and photographic modeling techniques are applied. As a result, a three-dimensional digital tool that supports decision-making processes and may be used in integrated digital spatial information systems and collaborative environments is developed.

1. INTRODUCTION

The application of integrated technologies for the digital documentation of infrastructures, as well as strategic buildings such as hospitals, government offices, and police headquarters, is an area of experimentation and interest for many disciplines.
On the one hand, there is a growing, although recent, interest in the integrated management of the full life cycle of infrastructures for the transport of products and people in the field of applied economic sciences, such as Asset Management (Garramone et al., 2022).
On the other hand, new fields of study such as City Information Modeling, CIM, demonstrate the increased attention towards the description and representation of all the different characteristics of the urban environment, both tangible and intangible, in order to define a shared knowledge and constraints system (Hbeich, 2019).
Many countries have implemented dedicated regulations to encourage digitization processes in support of more conscious, measurable decision-making processes with transferable consequences because of awareness of the challenges mentioned. In Italy, the digital transition process is the subject of a series of substantial regulatory updates starting with the New Public Contracts Code Legislative Decree 50/2016. Similarly, the subsequent Decrees, 'Baratono' No. 560/2017 and BIM Decree No. 312/2021 of the Ministry of Infrastructure and Transport and Sustainable Mobility underline the continuity of strategic objectives in the field of the application of integrated technologies to land management.
The most recent National Recovery and Resilience Plan (MISE, 2022) has further confirmed the strategic objective of digitising the construction sector and the central role of the Public Administration as a driver of development.
Even more so, the infrastructure network, railways, and others, on the national territory is lacking in investments dedicated to the implementation of mobility both in the direction of greater sustainability and the adaptation of the service to higher national standards. The introduction of innovations in the direction of increasing digitalization of mobility management operations is hampered by factors other than the territorial barriers. The shift to a more integrated administration of territories is not encouraged by, on the one hand, the low tendency for planned, if not preventive maintenance and, on the other hand, the natural obsolescence of some infrastructure portions (Mims, 2021). Finally, the presence of sections of railway infrastructure within the consolidated urban fabric, which is indicative of the stratification and evolution of the city in the nineteenth and twentieth centuries, necessitates additional economic resources for the complex management that is representative of the city's changes.
Therefore, as in the case study under examination, the development of regional railway lines also becomes a development and investment target featured in more modern infrastructure policies such as the PNRR.

2. RELATED WORKS

Only recently in Italy have conditions been created that make it possible to extensively apply the use of integrated digital technologies for surveying, representation, modeling and information management to the feasibility of the project life cycle. A digital revolution to improve the planning, implementation, and management of infrastructure and public building projects began in 2019 with reference to the Italian context. The establishment of statutory thresholds relating to the volume of work in public contracts for the application of BIM tools has increased interest in the use of integrated digital technologies on the part of PAs as well as professionals or architecture and engineering firms.

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The use of 3D terrestrial laser scanning and drone surveying technologies, HBIM modeling, information implementation, and digital data sharing environments is therefore beginning to become an essential prerequisite for bidding in public tenders. The opportunities offered both by regulatory requirements and by the increasing sustainability and accessibility of the technologies under consideration are leading to an increase in tenders regardless of the mandatory thresholds.
The OICE report on public tenders involving the use of BIM elected the Agenzia del Demanio as the most active public body, in the period 2019-2021, with over 235 BIM tenders issued. Italferr presents itself as the second main contracting station, for BIM tenders, although the total value of 1.2% of the total is still small (OICE, 2021).
For the first time, an extended approach to digital building documentation is being implemented.
The adopted solution falls under the category of public organizations that recognize the opportunities presented by current technologies before legal requirements, as in the case of the Agenzia del Demanio. In order to reduce risk, owners and managers of public real estate and infrastructure assets start the transformation processes within their organizations (Badenko et al., 2019). There are new opportunities to visualize and model information and data for different scales of intervention, as well as to connect data from multiple sources to the different phases of a work on existing assets' life cycle, from the intervention project to the construction site management, to operation and maintenance.

3. DEVELOPED METHODOLOGY

The procedure for collecting 3D survey data, defining overall data models, managing and implementing the information throughout time, and implementing the case study are all done in conjunction with FER and Ferrovie Emilia-Romagna, the third national railway infrastructure manager by network extension. On the national territory, FER manages 364 kilometers that serve the passenger and freight transportation markets, coming in behind Rete Ferroviaria Italiana, RFI, and Ferrovie del Sud-Est and ahead of Ferrovienord. The most significant construction site of the past ten years, in terms of geographical extension and allocated economic resources, begins in 2020 at FER.

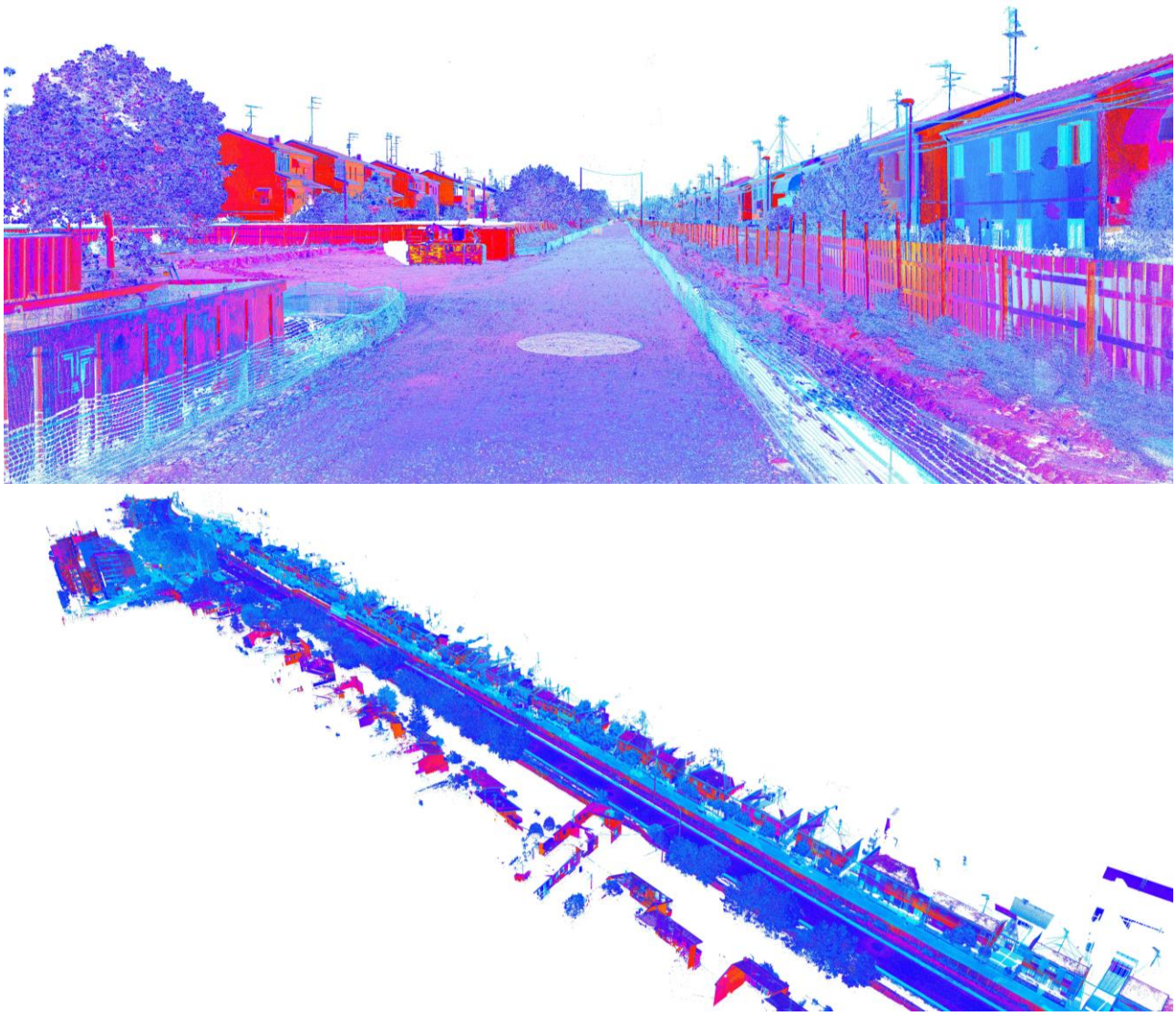

Figure 1. Views of the overall point cloud model of the new railway path.

Two railway lines that control the movement of people and products both locally and internationally along the southern and northern routes of the nation are being buried as part of this project. Since it is a highly populated area, the work, which is not yet finished, is intended to carry out an essential urban reconnection intervention by demolishing architectural and road barriers along the most crucial driveway entry to the city.
The relevance for the city of Ferrara of the infrastructure interventions described prompted FER to start a collaboration and experimentation with the local university for the digital management of interventions of a complex nature.
FER requested that a protocol be developed for the collection, modeling, and management of data that enables multi-scalar analyses, ranging from the analysis and comparison of the structural deterioration of the buildings before, during, and after the intervention to the verification of the excavation and construction site area during construction. In order to make the generated digital environment available for subsequent implementations, it is additionally necessary to combine various current data sets and information, including topographical data from earlier surveys and survey findings.

3.1 3D laser scanner survey

The generating and implementing of point clouds using 3D laser scanners for the purposes described is the product of a measurement protocol that, starting from the acquisition of polar coordinates, converts them into rectangular coordinates pertaining to a Euclidean space. The methodology adopted consists in the development of an integrated survey with several instrumental types of topographic type supported by navigable photographic type instruments, to respond to the prerequisites of immediate accessibility of visualisation and interrogation of certain information at different scales.
For this purpose, various technologies were integrated. A medium range time-of-flight scanner, Leica HDS C10, with a range of two hundred and fifty metres was used to survey the overburden of the entire area. The choice was dictated by the characteristic linear development and curvilinear junction typical of railway infrastructure landforms in urban areas.
Leica P40 3D laser scanner and BLK360 3D laser scanner, two additional terrestrial laser scanning technologies, were used to complete the integrated three-dimensional comprehensive survey in order to reach an accuracy level suitable for structural analysis of the building fronts facing the study area.
The geometric control in the various acquisition phases was guaranteed by independent primary substructures, for the south and north faces of the overburden area, of georeferenced cornerstones and by a second geometric structure of control points materialised by means of targets. The georeferencing and topographic survey were carried out using Leica GPS 1200 series and Leica TPS 1202 total station.
The three-dimensional survey by terrestrial laser scanner was also flanked by the acquisition of navigable spherical photos in order to meet the need for a multi-scale description of the geometric type, which guarantees the validity of the measurement at various scales (from general scale to scale of detail) and the visualisation of certain surface features that cannot be documented with topographic instruments and 3D laser scanners.
The described protocol allowed the hierarchization of the data into several orders of specific topographic weight and is therefore optimised for the calculation and verification of results. If, on the one hand, it is possible to push the control of the statistical values of the detailed survey to the maximum limit in a more restricted organised environment, while maintaining a high-quality control over the value of the systematic error and easily isolating any execution errors, on the other hand, the hyper determined rigid substructures are functional for the general calculation of the overall model construction.
Overall, the scan stations were realised with medium and small range 3D laser scanning instrumentation: 156 stationing points on approximately 1700 metres of linear development of the site: 36 inside the site area on the north side; 57 inside the site area on the south side and along the perimeter facing the road of the apartment building located at 135 Via Ippolito Nievo; 63 along Via del Bove.
Unlike the survey of a road structure in operation, the survey for the control of earthworks for the construction site of new infrastructures allows to operate under conditions of low impact and interference with the remaining work in progress. The low impact condition of the survey site is in fact guaranteed both by the technological innovations available today and by the survey design. In fact, an integrated approach based on the execution of first- and second-level geometric control networks makes it possible to control the noise and redundancy parameters of the data when compared to a morphological approach. This results in greater speed in the execution of field operations.

3.2 Topographic mapping grid and photo modelling survey

The design of the framing network considered, first, the complexity of managing an integrated system that assigns hierarchical relationships to measurement values, to which different geometric meanings and statistical weights are associated. The survey network is the basic structure on which all the subsystems necessary for the survey process rest and is the prerequisite for the geometric verification and numerical analysis phases.
The conformation of the network of cornerstones is structured in such a way as to contain, in its maximum extension, both the entire railway line and the context around it for approximately one thousand seven hundred metres of linear development, as well as all the identified sub-areas, i.e. the stationing points of the various instruments, in order to reduce the systematic angular error and keep the roto-translation statistics consistent with an overall closure value contained within a five millimetre interval.
Nonetheless, the integrated application of information on the state of the art from surveying by means of optical, photographic sensors is increasingly widespread due to the rapid technological development that characterises these technologies. However, the risk of a high level of inconsistency between the acquired photographic datum and the geometric datum, acquired through the integration of several three-dimensional surveying technologies, makes it necessary to apply protocols for the verification and testing of the datum.
An intrinsic characteristic of the photogrammetric survey is the two-dimensional nature of the acquisition datum, which through the superimposition of frames and knowledge of known coordinates allows for the reconstruction by means of projective methods, once the collinearity equations have been resolved, of a cloud of points consistent with an assigned coordinate system.
In the infrastructural field, the use of UAS systems (drones) for photo-documentation campaigns for the purpose of photo-modelling is frequent, as it is an instrumental methodology that enables the overcoming of obstacles in situ. Using high-resolution cameras with fixed focal lengths, a terrestrial photographic campaign was conducted to gather the photographic documentation. In fact, the morphological characteristics of the site made it possible to acquire all the necessary information relative to the material characteristics and structural degradation on the external fronts of the buildings.

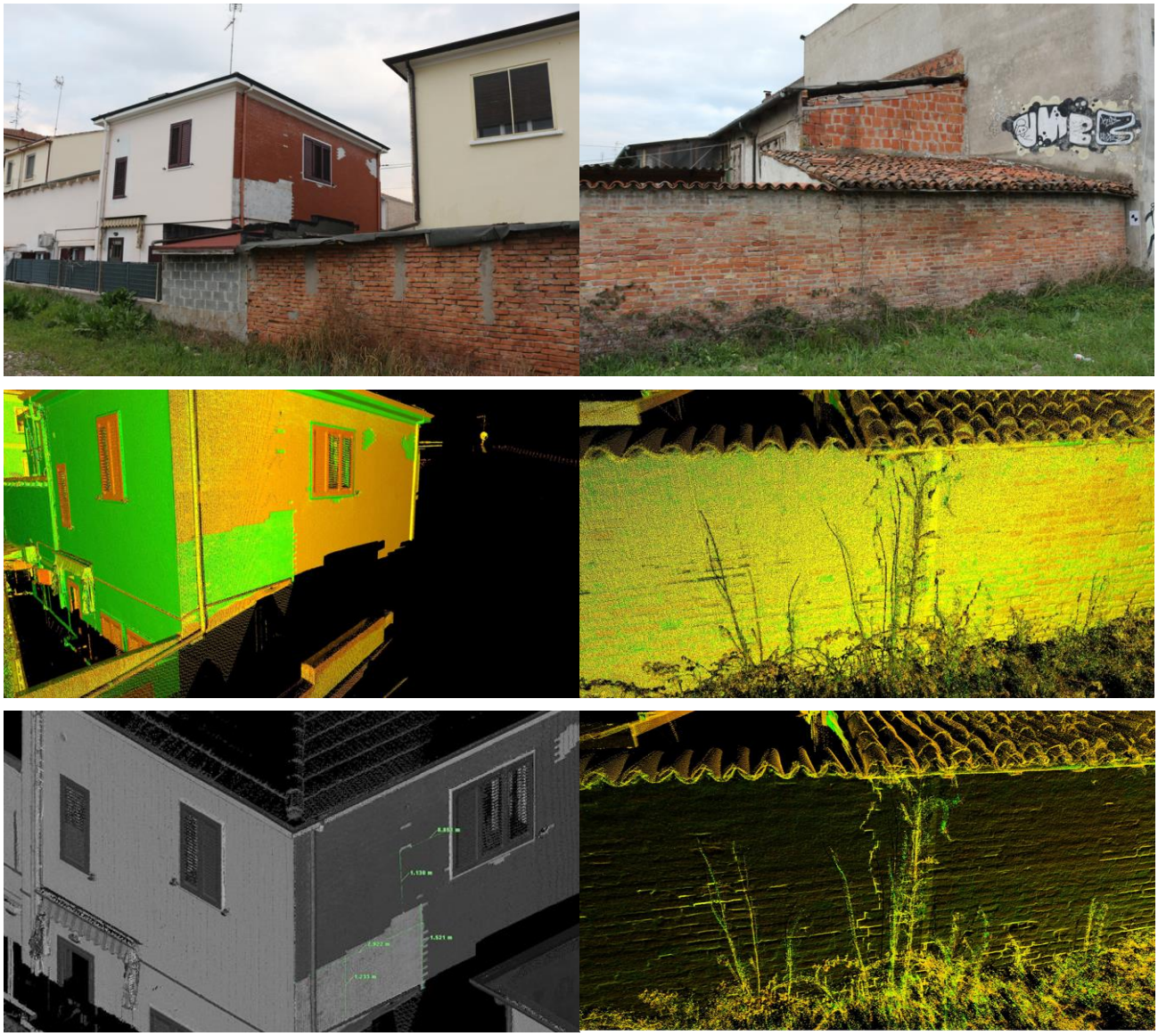

Figure 2. 3D point cloud model interrogation for detailed information: Scaled Framework for Analysis of Crack Propagation.

It was assumed that spherical, or rather panoramic, navigable images would be generated. These are structured images, composed of a swipe taken from the same viewpoint capturing perspective projections, then mounted in sequence to compose a single image projected onto a spherical reference surface. From a set of twelve coaxial frames with an angular pitch of fifteen degrees to cover the rounded angle for a single viewpoint, a single navigable elaborate is synthesised covering 360 degrees of visible space. Consequently, the navigation of the model related to the photographic database allows the simultaneous qualitative and quantitative evaluation of both superficial elements of buildings in the description of the state of wall faces and finishes evident and structural disruptions in place, cracking frameworks and spatial distortions are made possible on the same general model thanks to the high density of information and the characteristics of geometric type coordinates and the exploitation of reflectance.

3.3 Measurement model development and data management

The management of the integrated digital three-dimensional surveying protocols described is aimed at the formulation of an overall data model that fulfils the functions of both a metric-morphological database and a model for the extraction of representational works for the purposes of documentation, knowledge, design support and management of the of railway infrastructures in urban areas. As mentioned, the common interface for the entire process is the formulation of a point cloud model, appropriately processed and hierarchized.

The point cloud model developed is in fact composed of coherent point clouds with a single coordinate system. Through subsequent processing, the clouds are coherently superimposed, referring to a single system of coordinates, while remaining individually identifiable in order to be able to assess quality, nature of the data and statistical weight.

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The post-processing phases of the data therefore pursued the purpose of removing inconsistencies and instrumental data that can be classified, due to the intrinsic limitations of the sensors, as gross errors, as well as the elimination of data inconsistent with the purposes of the survey, such as the data related to the

transit flow in the proximity of the road network crossing the route under study.
The overall data model consists of 7,400,000,000 in geographical coordinates.

3.3 Medium and long-term fallout

Urban regeneration and social regeneration are, as well expressed by European policies, fundamental phenomena for developing strategies for the management, maintenance, and reconversion of the built heritage. Nonetheless, if developed in integration, they can constitute the driver for satisfying the needs, of a complex nature and in continuous and rapid change, that different social communities express with reference to the multiple current urban scenarios.
Consequently, the need to equip organisations in various ways involved in the value chain of intervention on the built environment with tools to support complex decision-making processes is becoming increasingly compelling. The application of integrated digital technologies therefore becomes an essential requirement to implement the analytics functionalities and Iot integrations indispensable to govern such complexity (Campos, 2020).
In the context described above, the renewed importance of information developed from integrated three-dimensional surveys fits in.
In fact, the need to implement, in a synchronic manner, multi-scalar surveys determine the central role of the survey project, which is called upon to respond to the need to enable readings from the territorial scale to the scale of architectural, structural detail or material characterisation of the external fronts of the urban scene.
A survey such as the one described is designed and executed to allow subsequent modelling, in scan to BIM processes, for example, for a LOG level of detail (with reference to the UNI 11337 standard). Such a level of detail, usually taken as a reference for the documentation and representation of conservation and restoration interventions, appears necessary today to guarantee the contextual verifications that intervention in an urban context requires.
However, the execution of a three-dimensional survey that meets the described requirements requires careful planning. In fact, the extensive application of integrated three-dimensional surveying and modelling technologies that the current context tends to favour requires renewed reflection on certain aspects.
Data redundancy, which is typical of a morphological approach to surveying, noise, and the weight of overall models are not only IT issues. The management of time and costs of execution, for public administrations, of the digital description phases of the state of art, will increasingly impose the use of automatic segmentation processes of certain information post-processing phases. The way in which the survey is carried out and the overall data model is calculated will therefore be of central importance in fostering automation processes. The challenge of the near future is therefore, also in the field of infrastructure management, the training of machine learning functionalities in order to test their effectiveness with reference to case studies similar to the context described and considered representative of management and maintenance, ordinary and extraordinary, as well as regeneration of the built environment.

Figure 3. Sequence of the twelve coaxial frames needed to perform the spherical image.

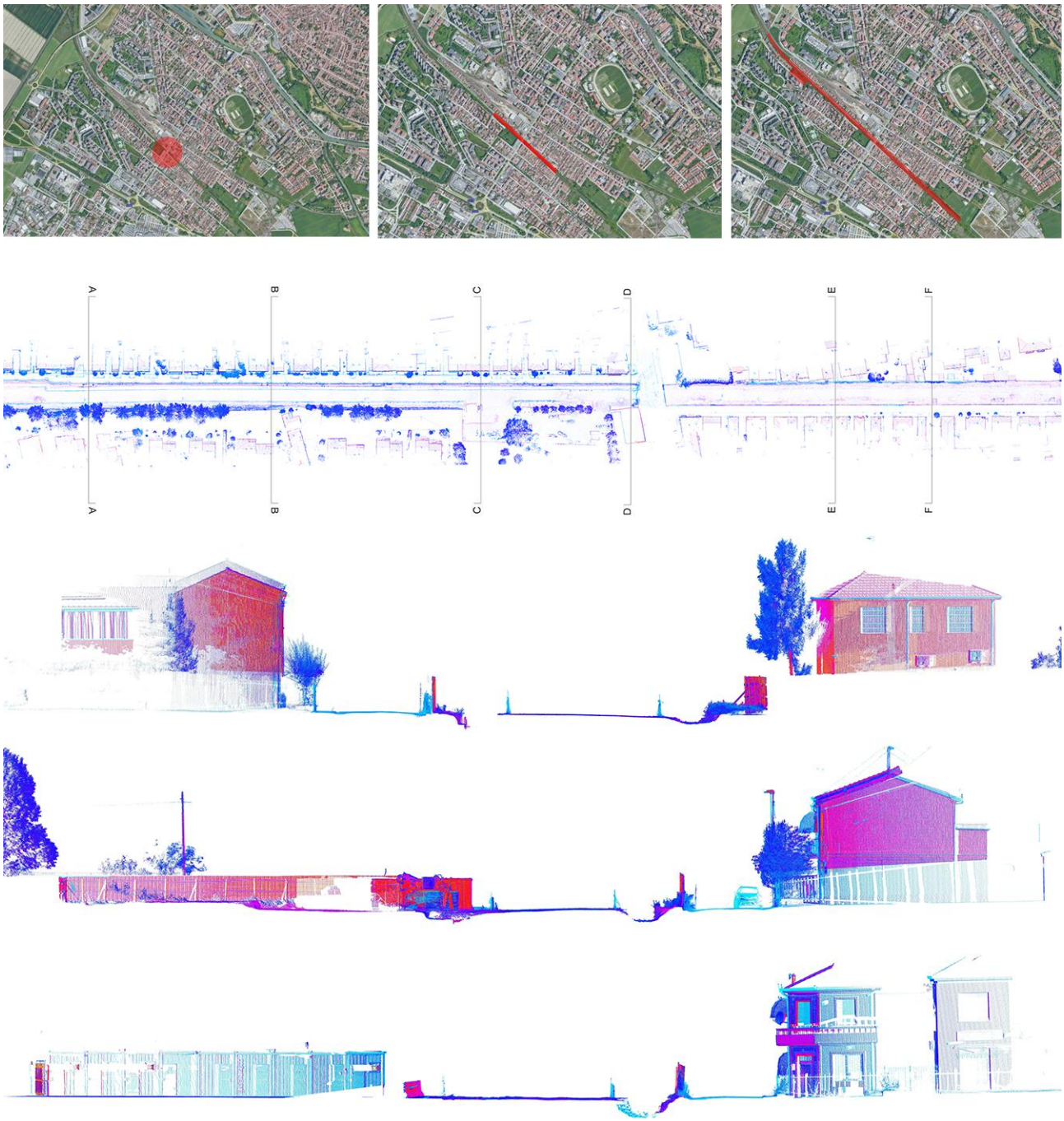

Figure 4. The information density and accuracy of the 3D database make it possible to query information from the urban scale to the scale of architectural detail.

Finally, experiments will be carried out with reference to policies supporting interventions to improve the energy performance and safety of the built heritage, in order to verify their effectiveness in operational terms.

4. CONCLUSIONS

Starting with a proper City Information Modeling, or UIM, approach, a data acquisition and processing protocol was defined that enables the different elements of the urban scene to be traced back to a geo-localized environment.
The urban scene is actually composed of multiple layers and elements that require a multi-scalar approach to project documentation.
Infrastructure, buildings, aggregates, the conservation and maintenance status of materials and components, as well as flows, networks, tangibles and intangibles, and citizen behavior, are all elements that define the urban landscape.
Nevertheless, the assessment of the behavioral and structural safety, as well as the energy behaviour of buildings and public spaces, has become a required prerequisite for many modifications, notably by public authorities.
In addition, other factors have accelerated the processes of documenting and understanding of the territory and urban fabric as well, in relation to the upgrading of seismic legislation.
The significant changes that built-up urban areas have undergone recently have increased interest in documentation-related concerns.

The subsequent push toward digitization has thus provided more comprehensive and efficient tools in terms of time, usability, and information accessibility.
The trend towards digitisation has also led to a rethink of the effectiveness of previously established documentation procedures, pushing towards a better integration of methods and protocols for surveying and digital representation.
In order to better integrate with other accurate 3d documentation techniques, the more established approaches that were characterized in previous decades by the deployment of technologies like GIS for documentation primarily at a territorial scale are now being reconsidered.
The case study shows how integrated three-dimensional survey protocols can allow, if appropriately structured, the construction of models capable of conducting multi-scalar analyses, from the territorial scale to the survey and documenting of the cracks on the external fronts of structures.
The use of integrated three-dimensional surveying technologies, from terrestrial laser scanning to photogrammetry, made it possible to define information datasets of multiple detail.
The overall point cloud model of the entire area is therefore associated, according to a semantic approach (Schilling, 2022) to the reading of the morphological and geometric elements, with DEM (Digital Elevation Model) of the area, detailed views at the scale of the building for the reading of structural instabilities and the photographic database organised on a metric basis.
However, the point cloud model remains, as also requested by the client, the main source of information to which the information datasets and individual coded elements remain correlated.
An approach of the type described in which it is the three-dimensional model resulting from the integration of direct and indirect surveying techniques that guides the interrogation, which is also made possible by open-source software, nevertheless implies the definition of specific prerequisites in order to develop information solutions that can be implemented over time.
In the case under examination, which is the result of research activities that have been underway for over a decade, the data acquisition and calculation phases have pursued the aims of: subsequent integration in integrated BIM and GIS environments (Barazzetti, 2017); verification of the maintenance of accuracy levels from urban to detailed scale in order to allow multiscalar readings; optimisation of the acquisition phases in order to control the noise and redundancy of the data, as well as to control the usability of the final overall data model; optimisation in the calculation phases in order to allow subsequent possible applications of automation processes for the semantic segmentation of the point cloud.
The result is a tool to support decision-making processes on the one hand and possible future modelling in a three-dimensional environment on the other, as well as implementations in more complex collaborative environments (Floros, 2019).
Several challenges, though, are still present.
First, related to the abilities required to use data sets and point cloud models.
Public administrations in especially keep relying on the production and use of static digital data, which is distinguished by poor information transferability and interoperability.
As a result, adoption of integrated digital information protocols is generally opposed. The few resources also committed to training the technical staff of public administrations acts as an additional obstacle to the admission of the aforementioned technologies and methodologies.
Integrated three-dimensional survey data may now play a different role in relation to the technological integration of BIM and GIS technologies, whereas in more recent years this deficiency could be partially attributed to the actual greater complexity, in terms of both hardware and software, connected with the use of point cloud models.

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