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Existing BIM to digitize and manage the built heritage in Campania Region

Existing BIM per la digitalizzazione e gestione del patrimonio edilizio della Regione Campania

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Summary

Abstract **1**

Sintesi **7**

Resumen **13**

1 Control BIM tools by asking the right questions **19**

1.1 WHY? An excessive waste of time and resources **19**

1.2 WHAT? A more efficient data management **21**

1.3 HOW? A broader perspective on BIM **27**

Functional aspects 30

Applications and functionalities 30

Accuracy and capability 33

Informational aspects and interoperability 36

Technical aspects 40

Organizational and legal aspects 43

Flow of definition in digitised processes 43

Procedural guidelines 46

The professional skills of the actors involved 47

BIM in Italian legislation 47

1.4 Setting the research within the proposed framework **48**

1.5 Remarks and conclusions **50**

References **52**

2 Documenting built heritage with BIM methodology **55**

2.1 The demand framework of Italian cities **55**

2.2 Road to E/HBIM **57**

2.3 The value of knowledge and case study analysis **59**

2.4 Requirement definition **62**

2.5 Technical aspects of BIM and model construction **63**

Survey project and data capture 64

Topography 65

Terrestrial laser scanning 68

Close-range photogrammetry 68

UAV photogrammetry 71

Data processing 73

Topography _______ 75
Terrestrial laser scanning _______ 76
Photogrammetry _______ 79
Low-level data integration _______ 91
Object recognition _______ 95
Stratification identification _______ 95
BIM modelling _______ 100
Semantic classing _______ 102
Preparation of the modelling phase _______ 106
2.6 Remarks and conclusions _______ **106**
References _______ **108**
3 Traceability in BIM processes for existing structures _______ ***111***
3.1 The uncertainties of geometric attributes _______ **111**
3.2 A methodological proposal _______ **112**
Detected accuracy _______ 112
Terrestrial laser scanning _______ 114
Photogrammetry _______ 116
Modelled accuracy _______ 116
3.3 Case study experimentation _______ **118**
Detected accuracy _______ 118
Terrestrial laser scanning _______ 118
Photogrammetry _______ 119
Modelled accuracy _______ 120
Accuracy reference labels _______ 121
3.4 Remarks and conclusions _______ **121**
References _______ **122**
Final notes _______ ***125***
Appendix A: survey tools and techniques _______ ***129***
Appendix B: information management plan (pGI) _______ ***143***
Appendix C: archival documentation _______ ***157***
Appendix D: results of the accuracy assessment _______ ***177***

List of Figures

Fig. 1. 1. Data loss caused by interruptions in the conventional flow (based on Eastman et al.).
Fig. 1. 2. Geometric and information attributes of a BIM object.
Fig. 1. 3. Contract interchange flow (based on national and international technical regulations).
Fig. 1. 4. Strategic information flow (based on ISO 19650 and UNI 11337).
Fig. 1. 5. BIM model across the entire building life cycle (based on Borrman).
Fig. 1. 6. Levels and forms of application for BIM methodology (based on Liebich et al.).
Fig. 1. 7. Relation between the different aspects of BIM (author's elaboration).
Fig. 1. 8. The seven 'dimensions', representing the main functionalities of a BIM model.
Fig. 1. 9. The three main standards on which BuildingSMART focuses.
Fig. 1. 10. IDM/MVD method used for the IFC-based exchange (based on Beetz et al.).
Fig. 1. 11. Creation process of a BIM model in new or existing buildings (author's elaboration).
Fig. 1. 12. Correlation between contract information flows (based on ISO 19650 and UNI 11337).
Fig. 1. 13. Content management in ACDat (based on UNI 11337-1:2017).
Fig. 1. 14. Comparison of planning effort and design decision (based on MacLeamy).
Fig. 2. 1. Direct (down) and reverse (up) engineering process (author's elaboration).
Fig. 2. 2. Mapping the area of interest on satellite images (based on Google Earth Pro image).
Fig. 2. 3. Mapping the area of interest on aerial photogrammetry (author's elaboration).
Fig. 2. 4. Scan-to-BIM (reverse engineering) workflow (author's elaboration).
Fig. 2. 5. Structure of the reference network used for the integration of the survey data.
Fig. 2. 6. Positioning of the post on the ST1 station centring nail with UAV target.
Fig. 2. 7. Checkerboard target distribution on the South-Eastern and North-Eastern facades.
Fig. 2. 8. Distribution of the checkerboard targets on the South-Western facade.
Fig. 2. 9. Evaluation of overlaps for the nadiral frame acquisition and UAV target selection.
Fig. 2. 10. Flight plan map with double grid and flight height for nadiral frames.
Fig. 2. 11. Search for matching encoded targets at two adjacent stations.
Fig. 2. 12. Top view of the UAV sparse cloud obtained from the structure estimation phase.
Fig. 2. 13. Choice of reference system consistent with input data.
Fig. 2. 14. Top view of the UAV error vectors from covariance matrix.
Fig. 2. 15. Correlation analysis between camera calibration coefficients.
Fig. 2. 16. Analysis of discrepancies between TLS cloud and photogrammetric models.
Fig. 2. 17. Chronological stratification of the first and second floors.
Fig. 2. 18. Chronological stratification of the ground floor and cellar.
Fig. 2. 19. Axonometric view and cross-section of the BIM model.
Fig. 2. 20. Semantic classing scheme of objects in the BIM model (author's elaboration).
Fig. 2. 21. Axonometric view and cross-section of the integrated point cloud.

Fig. 3. 1. Framework for tracking the accuracy of survey operations (author's elaboration).
Fig. 3. 2. Framework for tracking the accuracy of parametric modelling (author's elaboration).
Fig. C. 1. Title search from building registry of the real estate unit owned by di Filippo Rocco.
Fig. C. 2. Title search from building registry of the cellar owned by di Filippo Rocco.
Fig. C. 3. Title search from building registry of the real estate unit owned by di Filippo Maria.
Fig. C. 4. Title search from building registry of the cellar owned by di Filippo Maria.
Fig. C. 5. Extract 1 of the deed of sale between family members which allows an approximate dating of the original core of the building block.
Fig. C. 6. Extract 2 of the deed of sale between family members which allows an approximate dating of the original core of the building block.
Fig. C. 7. Extract 3 of the deed of sale between family members which allows an approximate dating of the original core of the building block.
Fig. C. 8. Building permit (Autorizzazione alla costruzione), dated to 28 December 1954, with a favourable opinion of the Municipality of Siano dated 21 March 1955.
Fig. C. 9. Design of the first extension to the building (plan, 1955-56).
Fig. C. 10. Design of the first extension to the building (facade, 1955-56).
Fig. C. 11. Planning permission (Licenza di sopraelevazione) protocol n° 3636 of 30 September 1960.
Fig. C. 12. Design of the second extension to the building (1960).
Fig. C. 13. Planning permission (Concessione edilizia, Registro costruzioni n° 2882, prot. n° 150 del 31 ottobre 1986).
Fig. C. 14. Planning permission (Concessione edilizia, Registro costruzioni n° 208, prot. n° 2885 del 3 dicembre 1992).
Fig. C. 15. Planning permission (Concessione edilizia, Registro costruzioni n° 21, prot. n° 4021 del 15 febbraio 1993).
Fig. C. 16. Planning permission (Concessione edilizia, Registro costruzioni n° 99, prot. n° 4021 del 6 ottobre 1995).
Fig. C. 17. Planning permission (Concessione edilizia, Registro costruzioni n° 89, prot. n° 4021 del 21 luglio 1997).
Fig. C. 18. Planning permission (Concessione edilizia, Registro costruzioni n° 13, prot. n° 4740 del 30 marzo 1999).
Fig. C. 19. Static inspection following work completed on 23 March 2000.

List of Tables

Table 1. 1. Correlation between LOD in different technical specifications.

Table 1. 2. General LOD scale from UNI 11337-4:2017.

Table 2. 1. Major BIM functionalities for existing buildings (based on Volk et al.).

Table 2. 2. Standard deviations on compensated vertex coordinates.

Table 2. 3. Summary of the main parameters and indicators of the SfM process.

Table 2. 4. Extract from the classification scheme of UNI 8290-1:1981 + A112:1983.

Table 2. 5. Scheme for identifying reliability levels of information content.

Table 3. 1. Combination of uncertainty sources for TLS survey.

Table 3. 2. Accuracy reference labels.

Table B. 1. Summary project identification.

Table B. 2. Acronyms in the document and their descriptions.

Table B. 3. Main normative references.

Table B. 4. Hardware infrastructure related to the different activities.

Table B. 5. Software infrastructure related to the different disciplines.

Table B. 6.Data exchange formats.

Table B. 7. Relative reference system for objects.

Table B. 8. Model goals with respect to the process phases.

Table B. 9. Digital graphical output.

Table B. 10. Normative references for security.

Abstract

It is now 48 years since Eastman theorized what would become known as BIM: Building Information Modelling. Despite this, we can observe that the methodology, together with its associated tools, is still considered an exception to established practice, an eternal novelty with clearly something unfinished.

If we exclude a few excellences, such as the United States and the United Kingdom, and countries vying for keeping up, such as France and Italy, there are still a lot of regions where BIM is completely unsystematized. As a result, it is first implemented in large design studios and public projects and only then, with difficulty, does it spread to the rest of the market.

While we could accept the idea of a silent revolution that takes time to gain a foothold, it is now clear that too much pressure has been applied to the AEC (Architecture Engineering Construction) sector, which was not ready for such a radical change, first in thought and then in practice. Putting this aside, the time required for innovation is in any case not compatible with that necessary for digitization in other sectors, generally between 5 and 10 years (NBS' 10th National BIM Report).

The fourth industrial revolution (Industry 4.0), the one of data and connections, has brought out the limits of our domain, which is unable to keep up with other sectors of production and services. While it is right that transition can only be triggered by an awareness of needs, it is also true that managing interactions with external fields is an equally relevant factor.

This paradigm can also be extended to the associated tools, which must interact and be connected to the web in order to ensure proper data management and the realization of the so-called "digital twin". The new AEC software has metabolized the BIM methodology, or at least it is oriented towards it, although consistent and significant examples are still linked to large projects and established professional actors.

There are no reports or analyses in the literature that disprove the inevitability of BIM for any product (infrastructure, buildings, etc.), application (new construction, renovation, restoration, etc.) or stakeholder (clients, designers, companies, etc.). Despite commercial maturity and a broad spectrum of technical standards that seem to be converging towards organicity, the most common image is that of an unfinished revolution.

Apart from the abovementioned excellences, we can identify an uncertain use of tools, very specialized, based on approximations through trial and error, accompanied by a limited knowledge of the IT (Information Technology) and complexity behind the software front-end. They are compounded by the weaknesses of a mistaken approach to change: on the one hand, there is a very fragmented experimentation, which has difficulties in dissemination and systemic interaction, and on the other hand, we have the inefficiency of a top-down body of rules and laws, which risks excluding the bottom from participation.

In this panorama, research can play a fundamental role in the dissemination and systematization, encouraging a rational use of tools that can go beyond contingent needs. A hybrid approach of practice and theory, spiced up with training in the basic principles of IT, might be the desirable solution.

If the AEC sector is not able to innovate and govern digital change, it will have to undergo it in order to adapt to this widespread need. The first experiments, which were strongly linked to IT innovations and software tools, have given way to an excessive theorization of the method which leaves us without any practical feedback, a sign of a general uncertainty in the direction to be taken.

A representative example of this lack is the answer to the need for sharing data, information and thus knowledge, a problem common to all disciplines. In the field of BIM, this critical issue is 'solved', in conceptual and normative terms, with the introduction of a dedicated digital environment, defined Common Data Environment (CDE) first in BS 1192-1:2007 and later in PAS 1192-2:2013. Since then, CDEs described by other standards have been proposed, together with those developed by the academic world and those promoted by software houses, capable of responding to the problem in different and not always compatible ways.

Similarly, the interaction between instruments cannot be left to the intensive work of the operator due to the inefficiency of software. The lack of an AEC ontology cannot be solved by using only IFC classes, which are incapable of pursuing targets incompatible with their nature. The transition to object-oriented programming, with its own specific elements, has not been completed in work scheduling and cost management appliances.

Not all the 7 'dimensions' of BIM can be realized. For example, we do not have Project Management (PM) tools capable of independently predicting possible interactions between modelled objects. When BIM is employed as a graphical support for administration, it does not always blend perfectly with data storage systems. Its tools are too often used to replace the old 2D representations (PDF or DWG), without the perception of a strategic and not just instrumental change.

Most of the focus for BIM is on new construction, with protocols being developed to make the production process more efficient. Its use concentrates on planning, design and integrated project delivery for buildings and infrastructure, but since recently, research interest shifted from earlier life cycle (LC) phases to maintenance, refurbishment, deconstruction, and end-of-life considerations, especially of complex structures. Promising benefits of efficient resource management motivate investigation to overcome uncertainties of building condition and deficient documentation, prevalent in existing heritage. A BIM protocol for the latter might end up as being very similar to the one applied for new constructions, but this might not be the most effective way of approaching the problem. The public debate on BIM is often confusing and on occasions lacks a clear vision on final goals.

To completely reformulate the problem and articulate it appropriately could be the first step to take to clarify the scenery just described. A tool in the gearbox of creative thinking is the so-called Kipling technique, whose archetypes can be found in the structure used by Greek-Roman philosophers to formulate the argumentations. It is a list of six seemingly trivial questions (5W+1H), yet they oblige you to re-examine each element or point of view with respect to a specific topic. The field of documentation and management of the built heritage is not an exception, and a deepening of the details, by articulating each answer in a complete way, can give an overview of the situation.

To be extremely concise, it can be observed that in the sector of architecture, engineering, and construction (Where?), data flows are today (When?) disorganized and productivity levels do not excel. This is because the world of construction, by its nature, is characterized by a certain level of disorder that does not allow a coordination of the figures involved in processes (Why?). Technicians (Who?) must therefore work hard to develop and adopt digital systems aimed at the effective and efficient management of the information at stake (What?).

If the Wh questions help to clarify and organize thinking, it is only with the H of "How" that we move on to action. How can we solve the problem, and especially how has it been addressed in literature? The BIM could be the answer to the first question if we critically analyse the many facets in which it has been presented since its introduction in the early 2000s.

As mentioned for CDEs, the biggest problem with BIM in relation to research is probably the fragmented treatment, which is unable to contribute to the definition of a best practice. The processes of creating a model can be completely different for new and existing buildings. In the first case, the purpose is to provide a product that is articulated in the different phases of the building's life cycle (ISO 22263:2008-R2017), from inception to demolition. As the implementation of such models is not complete, isolated solutions, designed for a specific purpose, are too often employed. For existing fabrics, depending on the availability of previously developed BIMs, the repository can be updated or re-created. In Italy, structures from the 1970s account for more than 60% of all constructions and they are mainly without documentation in digital format. Therefore, in practice, complex and costly reverse engineering processes are almost always used to retrieve the necessary information.

The panorama previously outlined is therefore very articulated and the complex of problems that derives from it can be more extensive. In order to provide solutions to the critical issues arising from a fragmented and differentiated treatment of the topic (BIM, Existing BIM, Historical/Heritage BIM), this research is oriented towards a broader dissertation, interpreting BIM as a system consisting of 4 interconnected elements:

- **functional aspects**; they analyse the capabilities or services provided by the BIM in the narrow sense (model construction) or by its accompanying software for data output. The functionalities can be internal (the 7 'dimensions') or connected to it through independent applications. Think of the structural calculation or any operation on specific requirements. This also includes analyses of the accuracy and efficiency of digital reproduction;

- **informational aspects and interoperability**; they include issues related to the structured organization of knowledge and data exchange, to ensure interoperability between different software systems without loss of information;
- **technical aspects**; they refer to the construction of the model and depend on the Level of Development (LOD) relative to the designated functionalities. Some examples are data acquisition, processing, object recognition, and modelling. The procedural pipeline can be differentiated between new and existing buildings;
- **organizational and legal aspects**; they define the general features of the model, the roles of the parties involved, their rights and responsibilities regarding information, their access to the model (reading and writing) or their obligation to provide a defined functionality.

The four elements just introduced are interconnected and can be interpreted as nodes of a graph (leaving out here the presence of some elements external to the system). The arcs that connect them can be grouped into two fundamental paths: the flow of information, which moves from the technical aspects towards the organizational ones, and the flow of definition, which has the opposite orientation. The former coordinates the transfer of data coming from the model, while the latter the instances that, after the processing of such information, define or update the model itself. To establish which of the two flows originates first is not simple and depends more on the characteristics of the object examined.

For what has just been said, two opposite expert categories are involved: on the one hand, those who operate in input, providing services for importing, acquiring, and monitoring data, transforming them into BIM models, and on the other, those who operate in output, producing reports or technical analyses (energy simulations, structural calculations, etc.). Once again, it is not easy to establish a hierarchy, as these are complementary roles within a cyclical process.

The framework presented here certainly does not claim to identify and analyse all aspects of the methodology, but is intended to provide a structured guide to reading the contents. All the proposed experiments can always be traced back to the four fundamental aspects described above. These will not be mere containers but will have the task of fostering the construction of connections between the elements investigated, an indispensable step for a systematization of the methodology.

The project follows two lines of research:

- the first is related to the technical aspects of BIM applied to existing constructions. The main objective is to formalize a procedural pipeline for re-

verse engineering implementations, especially with Scan-to-BIM techniques. Although the literature is rich in contributions analysing this topic, an organic treatment is lacking and there are many punctual experiences, related to the contingencies of the case study. Instead, our approach aims to generalize the results of applications and contribute to the outline of a best practice for the management of data derived from digital surveying. The proposed solutions attempt to foresee possible scenarios and offer valid alternatives to ensure a holistic treatment of the methodology. The structured organisation of models and outputs is not simply the product of factors emerging from the case study investigation, adapting to a wide range of situations without neglecting the requirements of current legislation and technical regulations. There is also no lack of in-depth studies on the processes of integrating survey data, mainly oriented towards low-level solutions, which are still not very widespread and therefore susceptible to refinement, contextualizing the conclusions with respect to design requirements. Downstream of the acquisitions and their processing, we devoted ourselves to object recognition as a preparatory and support phase for the semantic classification. Here again, the aim is to propose a cataloguing system that is flexible and compatible with building regulations;
- the second line of research focuses on the topics of data reliability and accuracy. The possibility of updating and reusing a model depends on precisely these two factors and, despite this, there is a lack of a unified framework to solve this critical issue. As far as the first topic is concerned, valid solutions emerge from the literature, but they struggle to establish themselves because they are not well integrated within the tools outlined by the technical standards. For this reason, our proposal for assessing reliability does not introduce any further novelties, but aims to seek out solutions already used in parametric modelling or related fields, reforming them if necessary and lightening the notional load on technicians, who could make use of tools they know and master. Turning to the subject of accuracy, the main proposals focus on the survey phases, presenting for modelling solutions that are either expeditious or in any case tied to the plug-ins of commercial software platforms. Alternatively, we suggest differentiated frameworks for survey operations and source-based virtualization, focused on statistical data processing and implementable in any workflow, without worrying about the specificities of the software used.

The choice of the case study is not random. The building block analysed, located in the historic centre of a municipality in the province of Salerno, stands out for its stratigraphic complexity and articulated relationship with the surrounding urban spaces. These elements, although strongly characterizing, fully reflect the qualities of many centres in Campania, produced by centuries-old stratifications. Moreover, they present a wide range of criticalities, both for the surveying and modelling phases, which allow us identifying and field-testing potentially the best solutions for the specificities of the case, contributing to enriching the range of experiences necessary to generalize the results of the research.

As far as the structure of the thesis is concerned, Chapter 1 reconstructs, through an in-depth study of the state of the art, the formation process of the BIM methodology, proposing a framework for the classification of its distinctive elements and framing within it the experiences of our own research path. Chapter 2 focuses on technical aspects, formalizing a workflow for Scan-to-BIM processes oriented towards correct semantic classification of information content and traceability of data implemented in the virtualization. Chapter 3 examines the issue of geometric attribute accuracy, proposing evaluation systems compatible with any case study, acquisition technique or parametric modelling platform. In conclusion, we critically analyse the objectives achieved and the possibilities of transferring the results.

Sintesi

Sono passati ormai 48 anni da quando Eastman teorizzò quello che sarebbe diventato noto come BIM: *Building Information Modelling*. Nonostante questo, possiamo facilmente constatare come questa metodologia, insieme agli strumenti associati, è ancora considerata un'eccezione alla pratica consolidata, un'eterna novità con chiaramente qualcosa di incompiuto.

Se escludiamo alcune eccellenze, come gli Stati Uniti e il Regno Unito, e Paesi che stanno cercando di tenere il passo con i tempi, come la Francia e l'Italia, ci sono ancora grandi aree del mondo in cui il BIM non è sistematizzato. Di conseguenza, è più facile registrare una sua diffusione a livello dei grandi studi di progettazione e soprattutto nell'ambito degli interventi pubblici, con non poche difficoltà di penetrazione nel resto del mercato.

Se da un lato potremmo accettare l'idea di una rivoluzione silenziosa che richiede tempo – troppo? – per prendere piede, dall'altro è ormai chiaro che troppa pressione è stata applicata al settore *AEC* (*Architecture Engineering Construction*), non ancora del tutto pronto a un cambiamento radicale, prima nella metodologia e poi nella pratica. A parte questo, il tempo richiesto per l'innovazione non è comunque compatibile con quello necessario alla digitalizzazione di altri comparti, generalmente compreso tra i 5 e i 10 anni (*NBS' 10th National BIM Report*).

La quarta rivoluzione industriale, la cosiddetta Industria 4.0, quella dei dati e delle connessioni, ha fatto emergere ancor di più i limiti dei questo settore, non sempre al passo con quelli della produzione e dei servizi; se è ovvio che la transizione possa essere innescata solo dalla consapevolezza dei bisogni, è anche vero che la gestione delle interazioni con gli ambiti esterni è un fattore altrettanto rilevante.

Questo paradigma può essere esteso anche agli strumenti associati, che devono interagire ed essere connessi al web per garantire una corretta gestione dei dati e la realizzazione del cosiddetto "gemello digitale". I nuovi software *AEC* hanno metabolizzato la metodologia BIM, o almeno sono orientati a essa, anche se esempi consistenti e significativi sono legati a grandi progetti e ad attori professionali affermati.

Non ci sono rapporti o analisi in letteratura che smentiscano l'inevitabilità del BIM per qualsiasi prodotto (infrastrutture, edifici, ecc.), applicazione (nuova costruzione, ristrutturazione, restauro, ecc.) o stakeholder (clienti, progettisti, aziende, ecc.). Nonostante la maturità commerciale e un ampio spettro di standard tecnici che sembrano convergere verso l'organicità, l'immagine più comune è quella di una rivoluzione incompiuta.

A parte le eccellenze, possiamo identificare ancora un uso incerto degli strumenti, molto specializzato, basato su approssimazioni per tentativi ed errori, accompagnato da una conoscenza limitata dell'informatica, grafica e non solo, e della complessità dietro il *front-end* del software. A ciò si aggiungono le debolezze di un approccio non corretto al cambiamento: da un lato c'è una sperimentazione molto frammentata, che ha difficoltà di diffusione e di interazione sistemica, e dall'altro abbiamo l'inefficienza di un corpo di regole e leggi, non sempre condiviso e che rischia di escludere l'utente finale dalla partecipazione.

In questo panorama, la ricerca può giocare un ruolo fondamentale nella diffusione e sistematizzazione, favorendo un uso razionale degli strumenti che possa andare oltre le esigenze contingenti. Un approccio ibrido di pratica e teoria, condito da una formazione sui principi base dell'informatica, potrebbe essere la soluzione auspicabile.

Se il settore *AEC* non è in grado di innovarsi e governare il cambiamento digitale, dovrà subirlo per adattarsi a questa esigenza diffusa. Le prime sperimentazioni, fortemente legate alle innovazioni informatiche e agli strumenti software, hanno ceduto il posto a un'eccessiva teorizzazione del metodo che ci lascia, spesso, senza alcun riscontro pratico, segno di una generale incertezza sulla direzione da prendere.

Un esempio rappresentativo di questa mancanza è la risposta alla necessità di condividere i dati, le informazioni e quindi la conoscenza, un problema comune a tutte le discipline. Nel campo del BIM questa criticità dovrebbe essere 'risolta', in termini concettuali e normativi, con l'introduzione di un ambiente digitale dedicato, definito *Common Data Environment* (*CDE*) prima nella BS 1192-1:2007 e poi nella PAS 1192-2:2013. Da allora sono stati proposti *CDE* descritti da altri standard, quelli sviluppati dal mondo accademico e quelli promossi dalle software *house*, capaci di rispondere al problema in modi diversi e non sempre compatibili.

Allo stesso modo, l'interazione tra strumenti non può essere lasciata all'intenso lavoro dell'operatore come effetto dell'inefficienza dei software. La mancanza di un'ontologia *AEC* non può essere risolta utilizzando solo classi *IFC*, incapaci di perseguire obiettivi incompatibili con la loro natura. Il passaggio alla programmazione orientata agli oggetti, con elementi specifici, non è stato completato nelle applicazioni di programmazione del lavoro e di gestione dei costi.

Non tutte le 7 'dimensioni' del BIM possono essere concretizzate. Per esempio, non abbiamo strumenti di *Project Management* (*PM*) capaci di prevedere indipendentemente le possibili interazioni tra gli oggetti modellati. Quando il BIM è usato come supporto grafico per l'amministrazione, non sempre si fonde perfettamente con i sistemi di archiviazione dei dati; i suoi strumenti sono troppo spesso utilizzati per sostituire le vecchie rappresentazioni 2D (PDF o DWG), senza la percezione di un cambiamento strategico e non solo strumentale.

La maggior parte dell'attenzione per il BIM è rivolta alle nuove costruzioni, con lo sviluppo di protocolli per rendere più efficiente il processo di produzione. Il suo uso si concentra sulla pianificazione, la progettazione e la consegna integrata di progetti per edifici e infrastrutture, ma da poco l'interesse della ricerca si è spostato dalle prime fasi del ciclo di vita alla manutenzione, ristrutturazione, decostruzione e dismissione, specialmente di strutture complesse. I promettenti benefici di una gestione efficiente delle risorse motivano l'indagine finalizzata al superamento delle incertezze correlate allo stato degli edifici e alla documentazione carente, prevalenti nel patrimonio esistente. Un protocollo BIM ad hoc potrebbe finire per essere molto simile a quello applicato per le nuove costruzioni, ma questo potrebbe non essere il modo più efficace di affrontare il problema. Infatti, il dibattito pubblico sul BIM è spesso confuso e a volte manca di una visione chiara degli obiettivi finali.

Riformulare completamente il problema e articolarlo in modo appropriato potrebbe essere il primo passo da approntare per chiarire lo scenario appena descritto. Uno strumento nell'ingranaggio del pensiero creativo è la cosiddetta tecnica Kipling, i cui archetipi si ritrovano nella struttura utilizzata dai filosofi greco-romani per formulare le argomentazioni. Si tratta di una lista di sei domande apparentemente banali (5W + 1H), che tuttavia obbligano a riesaminare ogni elemento o punto di vista rispetto a un argomento specifico. Il campo della documentazione e della gestione del patrimonio costruito non fa eccezione e un approfondimento dei dettagli, articolando ogni risposta in modo completo, può dare una visione d'insieme della situazione.

Per essere sintetici, si può osservare che nel settore delle costruzioni (Dove?), i flussi di dati sono oggi (Quando?) disorganizzati e i livelli di produttività non eccellono. Questo perché il mondo delle costruzioni, per sua natura, è caratterizzato da un certo livello di disordine che non permette un coordinamento delle figure coinvolte nei processi (Perché?). I tecnici (Chi?) devono quindi impegnarsi per sviluppare e adottare sistemi digitali finalizzati alla gestione efficace ed efficiente delle informazioni in gioco (Cosa?).

Se le 5W aiutano a chiarire e organizzare il pensiero, è solo con la H del "Come" che si passa all'azione. Come possiamo risolvere il problema, e soprattutto come è stato affrontato in letteratura? Il BIM potrebbe essere la risposta alla prima domanda se analizziamo criticamente le molte declinazioni in cui è stato presentato dalla sua introduzione nei primi anni duemila.

Come menzionato per i *CDE*, il più grande problema del BIM nel campo della ricerca è probabilmente la trattazione frammentata, incapace di contribuire alla definizione di una *best practice*. I processi di creazione di un modello possono essere completamente diversi per gli edifici nuovi e per quelli esistenti. Nel primo caso, lo scopo è quello di fornire un prodotto che si articola nelle diverse fasi del ciclo di vita dell'edificio (ISO 22263:2008-R2017), dall'ideazione alla demolizione. Poiché l'implementazione di tali modelli non è completa, troppo spesso si ricorre a soluzioni isolate, progettate per uno scopo specifico. Per i tessuti esistenti, a seconda della disponibilità di BIM sviluppati in precedenza, il repository può essere aggiornato o ricreato. In Italia, le strutture degli anni '70 rappresentano più del 60% di tutte le costruzioni e sono principalmente prive di documentazione in formato digitale. Pertanto, in pratica, si ricorre quasi sempre a complessi e costosi processi di ingegneria inversa per recuperare le informazioni necessarie.

Il panorama precedentemente delineato è quindi molto articolato e il complesso di problemi che ne deriva può essere più esteso. Per fornire soluzioni alle criticità prodotte da una trattazione frammentata e differenziata dell'argomento (BIM, *Existing*

BIM, *Historic/Heritage* BIM), questo lavoro si orienta verso una più ampia dissertazione, interpretando il BIM come un sistema composto da 4 elementi interconnessi:

- **aspetti funzionali**; analizzano le capacità o i servizi forniti dal BIM in senso stretto (costruzione del modello) o dal suo software di accompagnamento per l'output dei dati. Le funzionalità possono essere interne (le 7 'dimensioni') o collegate ad esso attraverso applicazioni indipendenti, si pensi al calcolo strutturale o a qualsiasi operazione su requisiti specifici, includendo anche l'analisi dell'accuratezza e dell'efficienza della riproduzione digitale;
- **aspetti informativi e interoperabilità**; comprendono questioni relative all'organizzazione strutturata della conoscenza e allo scambio di dati, per garantire l'interoperabilità tra diversi sistemi software senza perdita di informazioni;
- **aspetti tecnici**; si riferiscono alla costruzione del modello e dipendono dal livello di sviluppo (LOD) relativo alle funzionalità designate. Alcuni esempi sono l'acquisizione dei dati, l'elaborazione, l'identificazione degli oggetti e la modellazione. La *pipeline* procedurale può essere differenziata per i nuovi edifici e per quelli esistenti;
- **aspetti organizzativi e legali**; definiscono le caratteristiche generali del modello, i ruoli delle parti coinvolte, i loro diritti e responsabilità riguardo alle informazioni, il loro accesso al modello (lettura e scrittura) o il loro obbligo di fornire una funzionalità definita.

I quattro elementi appena introdotti sono interconnessi e possono essere interpretati come nodi di un grafo (tralasciando in questa sede la presenza di alcuni elementi esterni al sistema). Gli archi che li collegano possono essere raggruppati in due percorsi fondamentali: il flusso di informazione, che si muove dagli aspetti tecnici a quelli organizzativi, e il flusso di definizione, che ha l'orientamento opposto. Il primo coordina il trasferimento di dati provenienti dal modello e il secondo le istanze che, dopo l'elaborazione di tali informazioni, definiscono o aggiornano il modello stesso. Stabilire quale dei due flussi abbia origine per primo non è semplice e dipende più che altro dalle caratteristiche dell'oggetto esaminato.

Per quanto appena detto, due saranno le categorie di esperti coinvolte: da un lato quelli che operano in *input*, fornendo servizi di importazione, acquisizione e monitoraggio dei dati, trasformandoli in modelli BIM, e dall'altro quelli che operano in *output*, producendo relazioni o analisi tecniche (simulazioni energetiche, calcoli strutturali, ecc.). Ancora una volta, non è facile stabilire una gerarchia, poiché si tratta di ruoli complementari all'interno di un processo ciclico.

Il quadro qui presentato non ha certo la pretesa di identificare e analizzare tutti gli aspetti della metodologia, ma ha lo scopo di fornire una guida strutturata alla lettura dei contenuti. Tutte le sperimentazioni proposte sono sempre riconducibili ai quattro aspetti fondamentali descritti sopra. Questi non saranno semplici contenitori ma avranno il compito di favorire la costruzione di connessioni tra gli elementi investigati, passo indispensabile per una sistematizzazione della metodologia.

Il progetto segue due linee di ricerca:

- la prima è relazionata agli aspetti tecnici del BIM applicato alle costruzioni esistenti. L'obiettivo principale è quello di formalizzare una *pipeline* procedurale per le implementazioni di ingegneria inversa, specialmente con tecniche Scan-to-BIM. Sebbene la letteratura sia ricca di contributi che analizzano questo tema, manca una trattazione organica e sono presenti molte esperienze puntuali, legate alle contingenze del caso studio. Il nostro approccio vuole invece generalizzare i risultati della sperimentazione e contribuire al tracciamento di una *best practice* per la gestione dei dati derivanti dal rilievo digitale. Le soluzioni proposte cercano di prevedere i possibili scenari e offrono valide alternative per garantire un trattamento olistico della metodologia. L'organizzazione strutturata dei modelli e degli output non è il semplice prodotto di fattori emergenti dall'investigazione sul caso studio, adattandosi per questo a un ampio ventaglio di situazioni senza trascurare le richieste della legislazione e della normativa tecnica vigente. Non mancano, poi, approfondimenti sui processi di integrazione dei dati del rilievo, orientati principalmente a soluzioni di basso livello, ancora poco diffuse e quindi suscettibili di perfezionamento, contestualizzando le conclusioni rispetto alle esigenze progettuali. A valle delle acquisizioni e del loro trattamento, ci siamo dedicati alla *object recognition* come fase preparatoria e di supporto alla classificazione semantica degli oggetti parametrici. Anche in questo caso l'obiettivo è quello di proporre un sistema di catalogazione flessibile e compatibile con le prescrizioni normative in materia di edilizia;
- la seconda linea di ricerca si concentra sui temi dell'affidabilità e dell'accuratezza del dato. La possibilità di aggiornamento e riutilizzo di un modello dipende proprio da questi due fattori e, nonostante ciò, manca un framework unificato per risolvere questa criticità. Per quanto concerne il primo tema, dalla letteratura emergono soluzioni valide che tuttavia faticano ad affermarsi perché non sono ben integrate all'interno degli strumenti delineati dalle norme tecniche. Per questo motivo, la nostra proposta per la valutazione dell'affidabilità non introduce ulteriori novità ma si pone come obiettivo quello di ricercare soluzioni già utilizzate nell'ambito della modellazione parametrica o di settori affini, riformandole se necessario e alleggerendo il carico nozionistico gravante sui tecnici, i quali potrebbero avvalersi di strumenti che conoscono e padroneggiano. Passando al tema dell'accuratezza, le principali proposte si concentrano sulle fasi di rilievo, presentando per la modellazione soluzioni speditive o comunque vincolate ai *plug-in* delle piattaforme software commerciali. In alternativa, proponiamo framework differenziati per le operazioni di rilievo e virtualizzazione *source-based*, incentrati sul trattamento statistico dei dati e implementabili in qualunque flusso di lavoro, senza preoccuparsi delle specificità dei software impiegati.

La scelta stessa del caso studio non è casuale. Il blocco edilizio analizzato, localizzato nel centro storico di un comune della provincia di Salerno, si distingue per la complessità stratigrafica e l'articolata relazione con gli spazi urbani circostanti. Questi elementi, per quanto fortemente caratterizzanti, rispecchiano a pieno le qualità di molti centri campani, prodotti da stratificazioni secolari. Inoltre presentano un'ampia gamma di criticità, sia per la fase di rilievo che per quella di modellazione, che ci consentono di individuare e testare sul campo le soluzioni potenzialmente migliori per le specificità del caso, contribuendo ad arricchire la gamma di esperienze necessarie a generalizzare i risultati della ricerca.

Per quanto concerne la struttura della tesi, il Capitolo 1 ricostruisce, attraverso un approfondimento dello stato dell'arte, il processo di formazione della metodologia BIM, proponendo un *framework* per la classificazione dei suoi elementi distintivi e inquadrando in esso le esperienze proprie del nostro percorso di ricerca. Il Capitolo 2 si concentra sugli aspetti tecnici, formalizzando un flusso di lavoro per i processi Scan-to-BIM orientato alla corretta classificazione semantica dei contenuti informativi e alla tracciabilità dei dati implementati nel modello. Il Capitolo 3 esamina la questione dell'accuratezza degli attributi geometrici, proponendo sistemi di valutazione compatibili con qualsiasi caso studio, tecnica di acquisizione o piattaforma di modellazione parametrica. In conclusione, analizziamo criticamente gli obiettivi raggiunti e le possibilità di trasferimento dei risultati.

Resumen

Han pasado 48 años desde que Eastman teorizó por primera vez sobre lo que luego se conocería como BIM: *Building Information Modelling*. Pese a esto, la metodología y sus herramientas asociadas son consideradas una excepción a la práctica aún en la actualidad.

Excluyendo excepciones como Estados Unidos y Reino Unido, países como Italia y Francia intentan estar al día con la aplicación y el desarrollo de esta metodología, mientras que, en otras grandes regiones, el BIM aún no se encuentra sistematizado. Como resultado, su implementación inicial es factible en grandes estudios de diseño o proyectos públicos, mientras que hacia el resto del mercado se extiende con dificultad.

Si bien tarda en afianzarse, está claro que se ha ejercido demasiada presión sobre el sector de *AEC* (Arquitectura Ingeniería Construcción) para su implementación, que no se encontraba preparado para el cambio radical en el campo del pensar y del accionar. Dejando esto de lado, el tiempo de desarrollo de la innovación no ha sido compatible con el necesario para la digitalización en algunos sectores, tardando entre 5 y 10 años su implementación (*NBS' 10th National BIM Report*).

La cuarta revolución industrial (Industria 4.0), la de los datos y las conexiones, ha evidenciado los límites de nuestro sector, incapaz de equipararse al ritmo de la producción y los servicios. Si bien es cierto que la transición puede desencadenarse únicamente por la conciencia de las necesidades, también es cierto que la gestión de las interacciones con áreas externas es un factor relevante.

Este paradigma puede extenderse a herramientas asociadas, que deben de interactuar y conectarse a la web para garantizar una gestión correcta de los datos y la creación del denominado "gemelo digital". Los nuevos softwares *AEC* han metabolizado la metodología BIM, o al menos se encuentran orientados hacia ella, aun siendo ejemplos consistentes y significativos, se encuentran vinculados a grandes proyectos y actores establecidos.

No existen informes o análisis en la literatura que desestimen que el BIM puede ser utilizado para cualquier tipo de producto, aplicación o partes interesadas. Si bien la madurez comercial y el amplio espectro de estándares técnicos convergen en la organicidad, la imagen más común es la de una revolución inacabada.

Es posible identificar un uso incierto de herramientas, un uso especializado, basado en aproximaciones de prueba y error, acompañado de un conocimiento limitado de TI (Tecnologías de la Información) y de la complejidad detrás del *front-end* del software. A esto se le suma el agravante de un enfoque erróneo sobre el cambio: por un lado, una experimentación fragmentada con dificultades en la difusión e interacción sistémica, y por otro lado, la ineficacia de reglas y leyes, que ponen en riesgo la participación del usuario final.

En este panorama, la investigación juega un papel fundamental en la difusión y sistematización, favoreciendo el uso racional de herramientas que pueden ir más

allá de las necesidades. Un enfoque híbrido de práctica y teoría, con formación en principios básicos de informática, podría ser la solución.

De no ser capaz de innovar y dominar el cambio digital, el sector *AEC*, deberá de someterse a él para adaptarse a esta necesidad generalizada. Los primeros intentos ligados a innovaciones informáticas y herramientas de software han dado paso a la teorización del método que a menudo no es representado en un *feedback* práctico, lo que genera incertidumbre sobre el rumbo a seguir.

Un ejemplo de esta deficiencia es la necesidad de compartir datos, información y conocimiento, problema común en todas las disciplinas. En el campo de BIM, esta situación crítica se 'soluciona', en términos conceptuales y regulatorios, con la introducción de un entorno digital dedicado, definido como *Common Data Environment* (*CDE*) primero en BS 1192-1: 2007 y luego en PAS 1192-2: 2013. Desde entonces, se han propuesto *CDE* descritos por otros estándares, los desarrollados por el mundo académico y los promovidos por casas de software, capaces de responder al problema de formas diversas y no siempre compatibles.

Así mismo, la interacción entre herramientas no puede dejarse en manos del operador debido a la ineficiencia del software. La falta de una ontología *AEC* no puede solucionarse utilizando únicamente clases de *IFC*, incapaces de perseguir objetivos incompatibles con su naturaleza. La transición a la programación orientada a objetos, con elementos específicos, no se ha completado en aplicaciones de planificación de trabajo y gestión de costos.

No todas las 7 'dimensiones' de BIM pueden ser llevadas a cabo. Por ejemplo, no disponemos de herramientas de gestión de proyectos (*PM*) capaces de predecir de forma independiente las posibles interacciones entre los objetos modelados. Cuando es utilizado el BIM como soporte gráfico para la administración, no siempre se integra con los sistemas de almacenamiento de datos. Las herramientas se utilizan con frecuencia para reemplazar antiguas representaciones 2D (PDF o DWG), sin la percepción de un cambio estratégico y no solo instrumental.

La mayor parte de la atención en el BIM se centra en la nueva construcción, desarrollando protocolos para que el proceso de fabricación sea más eficiente. Si bien su uso se concentra en la planificación, el diseño y la entrega integrada de proyectos de construcción e infraestructura, el interés de la investigación ha migrado de las primeras etapas del ciclo de vida a las etapas del mantenimiento, renovación, demolición y desmantelamiento, especialmente aplicado a estructuras complejas. Los beneficios de la gestión eficiente de recursos, motiva la investigación para superar incertidumbres relacionadas con el estado de los edificios y la falta de documentación, que prevalecen en activos existentes. Un protocolo BIM para estos últimos, puede ser muy similar al aplicado para la obra nueva, pero puede que no sea la forma efectiva de abordar el problema. El debate público sobre BIM suele ser confuso y, en ocasiones, carece de una visión clara de los objetivos finales.

Reformular por completo el problema y articularlo adecuadamente podría ser el primer paso para aclarar el escenario que se acaba de describir. Una herramienta del pensamiento creativo es la llamada técnica de Kipling, cuyos arquetipos se encuentran en la estructura utilizada por los filósofos grecorromanos para formular los argumentos. Es una lista de seis preguntas aparentemente triviales (5W + 1H), que sin embargo nos obligan a reexaminar cada elemento o punto de vista respecto de un tema específico. El campo de la documentación y gestión del patrimonio construido no es una excepción y una profundización en los detalles, articulando cada respuesta de forma completa, puede dar un panorama de la situación.

Para ser extremadamente preciso, se puede observar que, en el campo de la arquitectura, la ingeniería y la construcción (*Where?*), los flujos de datos son hoy (*When?*) desorganizados y los niveles de productividad no sobresalen. Esto se debe a que el mundo de la construcción, por su naturaleza, se caracteriza por un cierto nivel de desorden que no permite una coordinación de las figuras que intervienen en los procesos (*Why?*). Los técnicos (*Who?*) deben, por tanto, comprometerse a desarrollar y adoptar sistemas digitales destinados a la gestión eficaz y eficiente de la información involucrada (*What?*).

Si las 5W ayudan a esclarecer y ordenar el pensamiento, es sólo con la H del "*How*" que entramos en acción. ¿Cómo podemos resolver el problema y, sobre todo, cómo ha sido abordado en la literatura? El BIM podría ser la respuesta a la primera pregunta si analizamos críticamente las múltiples variaciones en las que se ha presentado desde su introducción a principios de la década del 2000.

Como se mencionó para los CDE, el mayor problema con BIM en relación con la investigación es probablemente el tratamiento fragmentado, incapaz de contribuir a una buena práctica. Los procesos involucrados en la creación de un modelo pueden ser completamente diferentes para edificios nuevos y existentes. En el primer caso, el objetivo es proporcionar un producto que diferencie las fases del ciclo de vida del edificio (ISO 22263: 2008-R2017), desde su concepción hasta su demolición. Dado que la implementación de dichos modelos no es completa, con frecuencia se utilizan soluciones aisladas, diseñadas para un propósito específico. Para tejidos existentes, dependiendo de la disponibilidad de modelos BIM desarrollados previamente, se puede actualizar o recrear. En Italia, las estructuras de la década de 1970 representan más del 60% de las construcciones y en su mayoría no poseen documentación en formato digital. Por lo tanto, en la práctica, se utilizan procesos de ingeniería inversa complejos y costosos para recuperar la información.

El panorama esbozado anteriormente es, por lo tanto, muy complejo y el conjunto de problemas resultante puede ser aún más extenso. Para brindar soluciones a los problemas críticos producidos por un tratamiento fragmentado y diferenciado del tema (BIM, BIM existente, BIM histórico/patrimonial), esta investigación se orientará hacia una disertación más amplia, interpretando BIM como un sistema compuesto por 4 elementos interconectados:

- **aspectos funcionales**; analizan capacidades o servicios proporcionados por el BIM en sentido estricto (construcción de modelos) o por el software para la salida de datos. Las funcionalidades pueden ser internas (las 7 'dimensiones') o conectadas a través de aplicaciones independientes como, por ejemplo, el cálculo estructural o cualquier operación que requiera requisitos específicos; donde se incluye el análisis de la precisión y eficiencia de la reproducción digital;

- **aspectos de información e interoperabilidad**; relacionados con la organización estructurada del conocimiento y el intercambio de datos, para asegurar la interoperabilidad entre diferentes sistemas de software sin pérdida de información;
- **aspectos técnicos**; referidos a la construcción del modelo y dependen del nivel de desarrollo (LOD) relacionado con las funcionalidades designadas. Algunos ejemplos son la adquisición de datos, el procesamiento, la identificación de objetos y el modelado. El flujo de trabajo se puede diferenciar para edificios nuevos y existentes;
- **aspectos organizativos y legales**; definen las características generales del modelo, los roles de las partes involucradas, sus derechos y responsabilidades en relación con la información, su acceso al modelo (lectura y escritura) o su obligación de proporcionar una funcionalidad definida.

Los elementos presentados se encuentran interconectados y pueden ser interpretados como nodos de un grafo (omitiendo la presencia de algunos elementos externos al sistema). Los arcos que los conectan se pueden agrupar fundamentalmente de dos maneras: el flujo de información, que se mueve desde los aspectos técnicos hacia los organizacionales, y el flujo de definición, que tiene la orientación opuesta. El primero coordina la transferencia de datos provenientes del modelo y el segundo las instancias que, luego de procesar esta información, definen o actualizan el propio modelo. Establecer cuál de los dos flujos se origina primero no es fácil y depende en gran medida de las características del objeto examinado.

Existen dos categorías de expertos implicados, por un lado, los que operan in *input*, prestando servicios de importación, adquisición y seguimiento de datos, transformándolos en modelos BIM, y por otro lado los que operan in *output*, elaborando informes o análisis técnicos (simulaciones energéticas, cálculos estructurales, etc.). Entre ambos, no es fácil establecer una jerarquía, ya que son roles complementarios dentro de un proceso cíclico.

El marco que aquí se presenta no pretende ciertamente identificar y analizar todos los aspectos de la metodología, sino que pretende ofrecer una guía estructurada para la lectura de los contenidos. Todos los experimentos propuestos se pueden remitir siempre a los cuatro aspectos fundamentales descritos anteriormente. No serán meros contenedores, sino que tendrán la misión de fomentar la construcción de conexiones entre los elementos investigados, paso indispensable para una organización de la metodología.

El proyecto sigue dos líneas de investigación:

- el primero está relacionado con los aspectos técnicos de BIM aplicados a las construcciones existentes. El objetivo principal es formalizar un procedimiento para las implementaciones de ingeniería inversa, especialmente con técnicas de Scan-to-BIM. Aunque la literatura es abundante en contribuciones que analizan este tema, falta un tratamiento orgánico y hay muchas experiencias puntuales, relacionadas con las contingencias del caso de estudio. En cambio, nuestro enfoque pretende generalizar los resultados de la experimentación y contribuir a esbozar una práctica óptima para la gestión de los datos derivados de la topografía digital. Las soluciones propuestas intentan prever posibles escenarios y ofrecer alternativas válidas para garantizar un tratamiento holístico de la metodología. La organización estructurada de los modelos y los resultados no es simplemente el producto de los aspectos que surgen de la investigación del caso de estudio, adaptándose a una amplia gama de situaciones sin dejar de lado los requisitos de la legislación y las normas técnicas vigentes. Tampoco faltan estudios en profundidad sobre los procesos de integración de los datos de levantamiento, orientados principalmente a soluciones de bajo nivel, todavía poco extendidas y, por tanto, propensas a ser perfeccionadas, contextualizando las conclusiones con respecto a los requisitos de diseño. Tras las adquisiciones y su procesamiento, nos dedicamos al reconocimiento de objetos como fase preparatoria y de apoyo a la clasificación semántica de los objetos paramétricos. También en este caso, el objetivo es proponer un sistema de catalogación flexible y compatible con la normativa de construcción;
- la segunda línea de investigación se centra en las cuestiones de fiabilidad y precisión de los datos. La posibilidad de actualizar y reutilizar un modelo depende precisamente de estos dos factores y, a pesar de ello, se carece de un marco unificado para resolver esta cuestión crítica. En cuanto a la primera cuestión, surgen soluciones válidas en la literatura, pero les cuesta consolidarse porque no están bien integradas en las herramientas que marcan las normas técnicas. Por ello, nuestra propuesta de evaluación de la fiabilidad no introduce más novedades, sino que pretende buscar soluciones ya utilizadas en la modelización paramétrica o en campos afines, reformándolas si es necesario y aligerando la carga nocional de los técnicos, que podrían hacer uso de herramientas que conocen y dominan. En cuanto al tema de la precisión, las principales propuestas se centran en las fases de levantamiento, presentando para la modelización soluciones expeditivas o, en cualquier caso, vinculadas a los *plug-ins* de las plataformas informáticas comerciales. Como alternativa, proponemos *frameworks* diferenciados para las operaciones de levantamiento y la virtualización *source-based*, centrados en el procesamiento de datos estadísticos e implementables en cualquier flujo de trabajo, sin preocuparse por las especificidades del software empleado.

La elección del caso de estudio no es azarosa. El bloque de edificios analizado, situado en el centro histórico de un municipio de la provincia de Salerno, destaca por su complejidad estratigráfica y su relación articulada con los espacios urbanos circundantes. Estos elementos, aunque fuertemente característicos, reflejan plenamente las cualidades de muchos centros de Campania, producidas por estratificaciones seculares. Además, presentan una amplia gama de criticidades, tanto para la fase de encuesta como para la de modelización, que permiten identificar y probar sobre el terreno las soluciones potencialmente mejores para las especificidades del caso, contribuyendo a enriquecer el abanico de experiencias necesarias para generalizar los resultados de la investigación.

En cuanto a la estructura de la tesis, el Capítulo 1 reconstruye, a través de un estudio en profundidad del estado del arte, el proceso de formación de la metodología BIM, proponiendo un marco para la clasificación de sus elementos distintivos y enmarcando en él las experiencias de nuestra propia trayectoria investigadora. El Capítulo 2 se centra en los aspectos técnicos, formalizando un flujo de trabajo para los procesos de escaneado a BIM orientado a la correcta clasificación semántica del contenido de la información y la trazabilidad de los datos implementados en el modelo. El Capítulo 3 examina la cuestión de la precisión de los atributos geométricos, recomendando sistemas de evaluación compatibles con cualquier caso de estudio, técnica de adquisición o plataforma de modelización paramétrica. Como conclusión, se analizan críticamente los objetivos alcanzados y las posibilidades de transferencia de los resultados.

1 Control BIM tools by asking the right questions

1.1 WHY? An excessive waste of time and resources

The digitisation occurred in recent years has transformed a wide range of industrial sectors, thus leading to a huge increase in productivity, quality, and item variety. In the AEC domain, digital tools are widely employed to design, construct, and manage buildings and infrastructure. However, the continuous use of digital information along the entire process chain lags far behind other industries. Valuable data is often lost because it is mostly delivered in the form of drawings, either printed on paper or in a digital but limited format, imitating the age-old way of working using a drafting board. These interruptions in the knowledge and negotiation flow occur throughout the entire life cycle of a built facility: in its design, construction, and operation phases, as well as in the handovers between them.

Line drawings cannot be fully interpreted by computers. The information they contain can only be partially processed by computational methods. Basing the knowledge and negotiation flow on drawings alone therefore fails to exploit the great potential of technology to support project management and building operation. A key problem is that the consistency of different technical drawings can only be checked manually. This is a potentially huge source of errors, particularly when we consider that drawings are typically created by experts from different disciplines and multiple companies. Changes to the design are particularly challenging: if they are not continuously tracked, inconsistencies can easily arise and they are often not discovered until actual construction.

The reduced depth of information in technical drawings also has a significant disadvantage in that the acquired knowledge cannot be used directly by downstream applications for any kind of analysis, calculation, and simulation, but must be re-added manually, requiring additional work and exposing to possible errors. The same applies to the delivery to the owner after the end of construction. He must invest considerable effort in extracting the necessary instruction from the drawings and documents and entering it into a facility management system. At each of these exchange points, data that was once available in digital form is lost and has to be painstakingly recreated (Fig. 1. 1 [1]).

In this context, BIM can come into play. By applying the methodology, a deeper use of communication technology in the design, engineering, construction, and operation of built structures is realised. Instead of storing information in drawings, BIM memorizes, maintains, and exchanges it uses complete virtualization of products and processes as the main information vehicles, possibly accompanied by other digital outputs. This approach dramatically improves the coordination of design activities, the integration of simulations, the setup and control of the construction process, as well as the delivery to the operator. By minimising manual data re-entry and allowing the subsequent re-use of them, laborious and error-prone work is avoided.

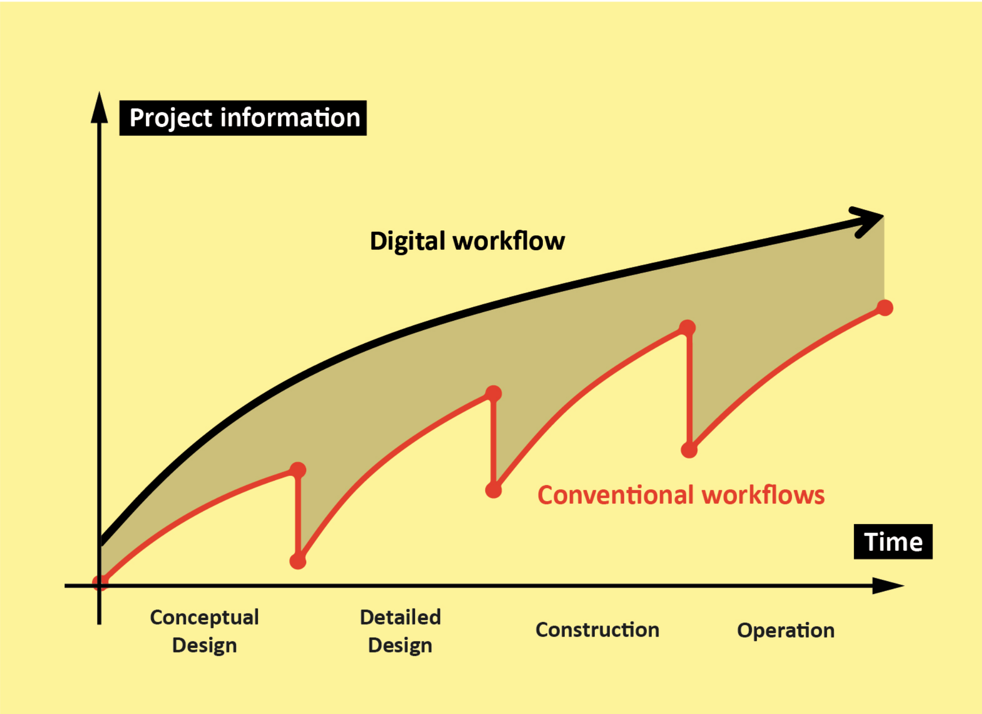

Fig. 1. 1. Data loss caused by interruptions in the conventional flow (based on Eastman et al.).

Many sectors, such as the automotive industry, have already completed the digital transition with positive results [2]. The AEC domain, however, has its own challenging boundary conditions: first, the process and value creation chain are not controlled by a single company, but are dispersed across many firms, including architectural offices, engineering consultancies, and construction companies. They typically co-operate only for the duration of a single project and not for a longer period. Consequently, there are many interfaces in the network of companies where digital information must be delivered. Since these knowledge and negotiation flows must be supervised and controlled by a central instance, the onus is on the building owner to specify and enforce the use of BIM methodology, anything but an easy task.

1.2 WHAT? A more efficient data management

According to the UNI 11337-1:2017 standards, in the construction sector the transfer of knowledge and negotiation between the parties involved in any process (design, production, execution and decommissioning) must take place through cognitive elements which, in order of increasing relational complexity, are data, information and informative content.

To fully digitise operations, it is preferable for data to be structured, related, and worked electronically, fixed on digital media, and written in open format. They can be expressed graphically (by signs), alphanumerically (by symbols) and in multimedia (by images and sounds).

While this helps us to organize and relate the knowledge we possess through appropriate vehicles (models and outputs) and to understand the minimum requirements for communication between the actors involved, it does not clarify which attributes (geometric or otherwise) to refer to when virtualising or representing physical or spatial entities and processes.

The most obvious attribute virtualised by a BIM object is the three-dimensional geometry of the structure being designed or built, which provides the basis for performing clash detection and deriving consistent horizontal and vertical sections (Fig. 1. 2). It is worth noting, however, that geometry alone is not sufficient to provide a truly capable virtualization. One of the main features of a Building Information Model is its ability to convey semantics. This implies that all its objects possess meaning, i.e., they are instances of entity types such as a wall, a column, a window, a door and so on. These objects combine a parameterised geometric representation with further descriptive properties and relationships to other elements of the virtualization. Working with objects is a prerequisite for using the model for any kind of analysis, including structural or building performance simulations. Furthermore, it is also necessary to derive drawings that comply with the technical regulations, usually requiring abstract or symbolised representations that cannot be produced by 3D geometry alone.

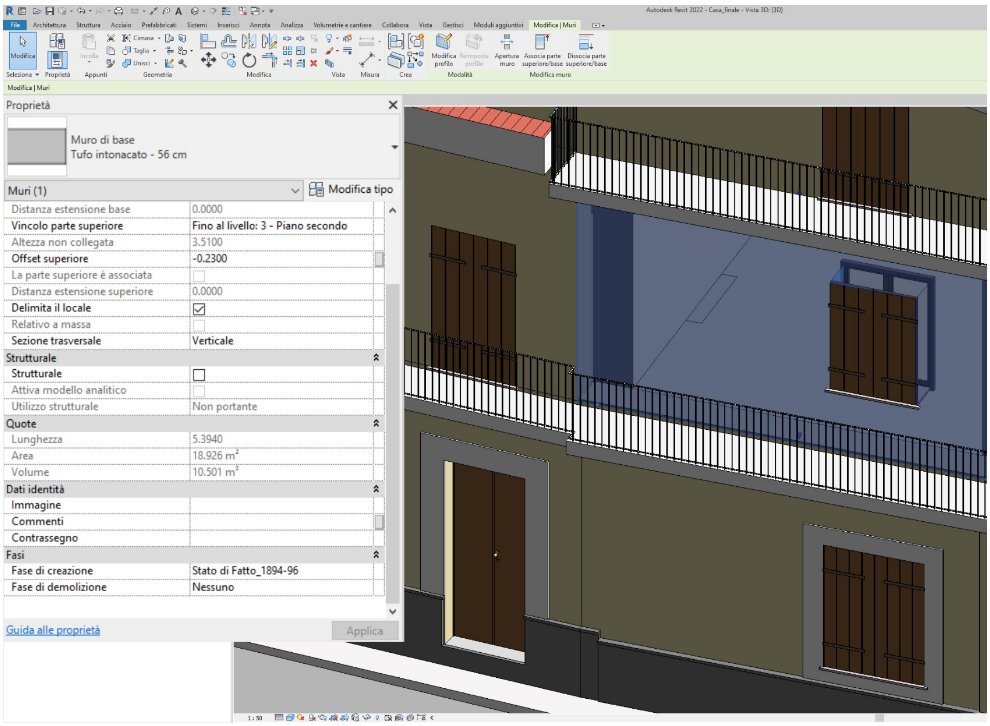

Fig. 1. 2. Geometric and information attributes of a BIM object.

There is no universally enforceable definition of what information a BIM model should provide. The current technical standards (in Italy UNI 11337-4:2017) mainly refer to new buildings, completely leaving out the existing structures. Instead, the specific content strongly depends on the purpose of the virtualization, i.e., its functional aspects. Indeed, the intended use cases provide an important starting point for the execution of the BIM project and must be defined already in the programming phase. In literature there are many examples that group possible applications according to building life cycle stage. In the most common cases, several BIM models are employed across project phases, each adapted to a specific function.

The definition of a more effective approach first requires the development of an information structure for the final product and for the process, intended as a set of actions carried out for the development of the project and therefore as an intangible aspect of the product itself. With regard to the latter, PAS 1192-2:2013 and PAS 1192-3:2014 regulations (UK) identify the Development stage (CAPEX - strategy, feasibility, design, construction) and the Execution stage (OPEX - management, maintenance, restoration, requalification, demolition), while reaffirming their close mutual dependence. Consequently, models have both a regulatory function for production (Project Information Model - PIM) and an identification function of the actual situation and of the time flow about existing products (Asset Information Model - AIM) as well. This duality has been fully transposed by UNI 11337-1:2017, emphasizing the beginning-end relationship between the two stages, which in turn can be divided into multiple phases. It is worth mentioning that, at least in the current public works system in Italy, there is no direct correlation between the above aspects and design levels. Stages and phases are instead linked to the goals of the process, from which then descend the targets of the model and its objects (LOD).

Knowledge systematization requires the definition of an interchange flow. In a broader vision of BIM, free from the specific features of a case study or a processing software, we could imagine two complementary flows: one of information, which comes from the model and allows it to perform its functions, and one of definition, which articulates and updates it.

The latter is related to the contract document flow, aimed at identifying the recognition purposes of the process. Certainly, the best known is the one defined in the United Kingdom, which is also inherited from the Italian technical regulations (UNI 11337-5:2017, UNI/TR 11337-6:2017) and consists of three phases:

1. Employer Information Requirement (EIR), a document or data container that expresses the request for information and sets the rules for the dialogue between the involved parties.
2. BIM Execution Plan - pre contract (pre-BEP), a proposal for managing the proffered information based on the client's requirements (EIR) and on the tenderer's standard abilities.
3. BIM Execution Plan - post contract (post-BEP), a scheme for managing the information agreed upon based on the client's requirements (EIR) and on the tenderer's particular abilities verified and redefined since the specific contract and client.

For a long time, it was thought that the American structure consisted only in the final contractor's BIM order (post BEP). Instead of having BEP, it has BPxP (BIM Project eXecution Planning) and is part of an exchange process that is identical, apart from the name, to the UK flow (Fig. 1. 3). An analogous discourse can be made for Italy (*CI* - *oGI* - *pGI*).

Regardless of the specific regulation, we can observe how, downstream of an initial definition cycle, a flow of information is generated to achieve the required goals. Establishing a hierarchy within the two flows and who is responsible for the formation of the other is not a simple matter (and probably not even a priority), depending to a large degree on the characteristics of the object examined. The most relevant aspect is that their complementarity and cyclicity allows the BIM model to enrich and evolve along the phases of the building life cycle.

However, the documents presented above are only the tip of the iceberg in the new information management paradigm and always refer to the individual contract, intervention, or order. Upstream and downstream of the latter, procedures,

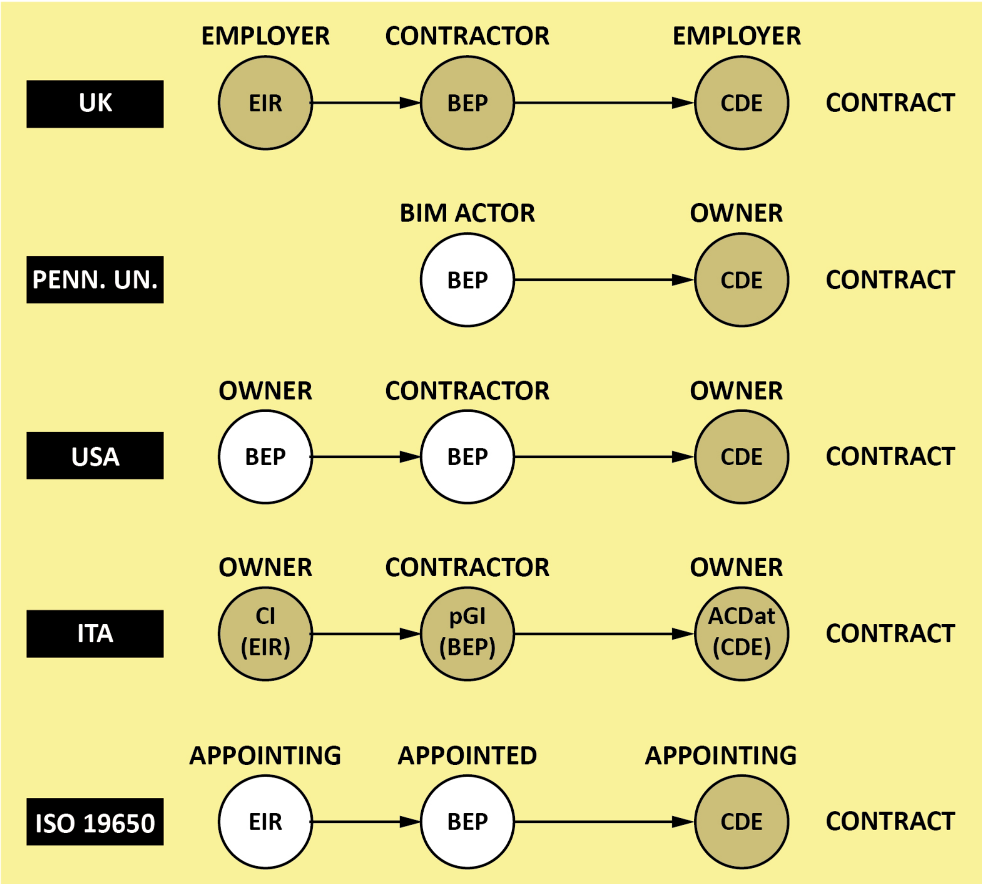

Fig. 1. 3. Contract interchange flow (based on national and international technical regulations).

tools, and documents of a strategic nature are also required, underlying the area of visibility of the intervention, which are indispensable for the construction of a truly organic information management system (Fig. 1. 4). There is, consequently, a need to regulate not only individual orders, but also the entire information structure of groups involved in any BIM process.

These requirements are embodied in a new document, the Organization Information HandBook (OIB), a tool whose parts contain many references to existing standards. However, these elements need to be reorganized and systematized in order to create an organic container. Although this manual is an innovation, it is rooted in a significant substratum of standardised rules, which are already present and partly consolidated. These ones originate in PAS 1192 and are confirmed in UNI EN ISO 19650. In addition to the already mentioned EIR, BEP and CDE, PAS 1192 (parts 2 and 3), in fact, introduces specific information rules that go beyond the single intervention (Project), affecting:

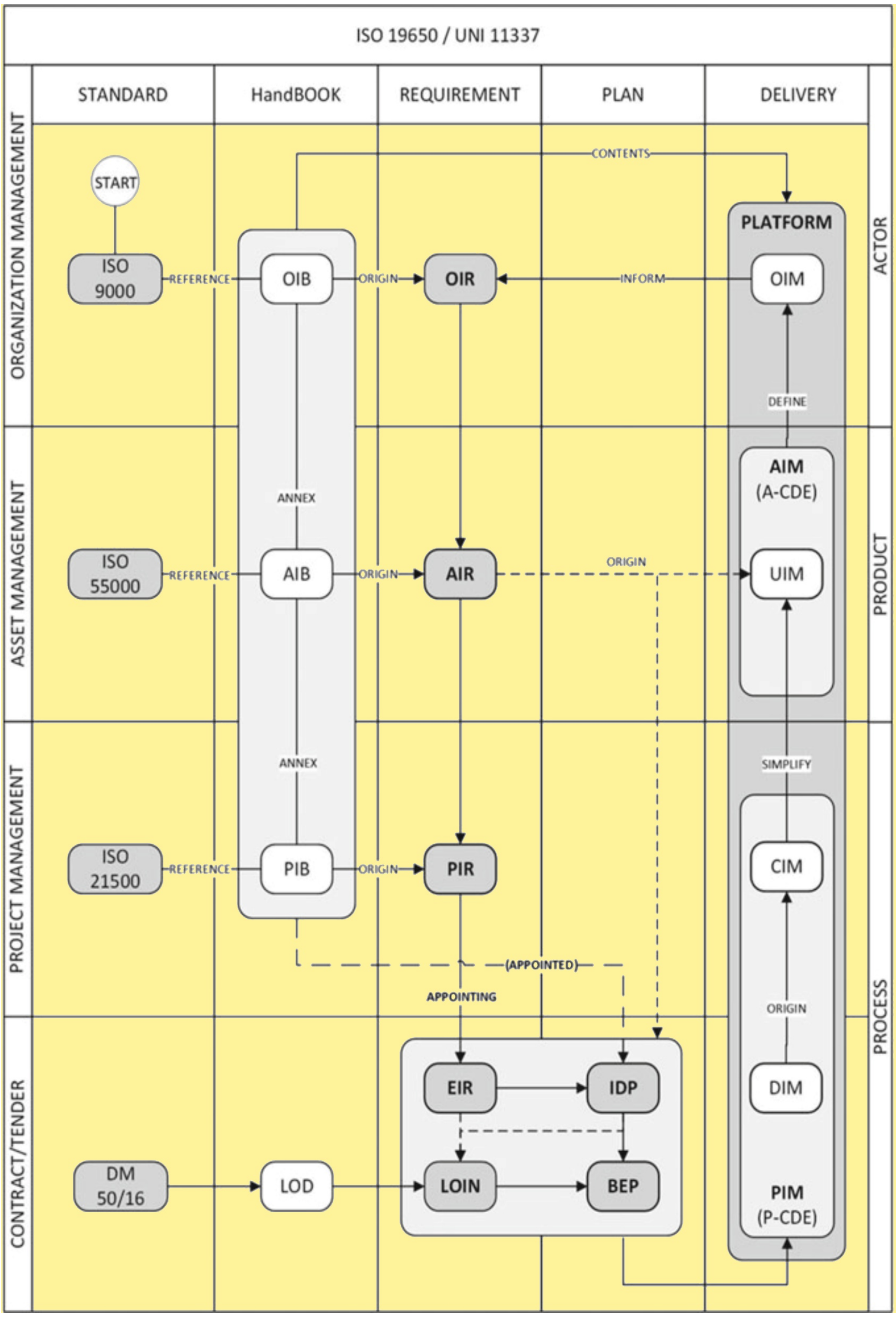

Fig. 1. 4. Strategic information flow (based on ISO 19650 and UNI 11337).

- the property portfolio, towards which the actions are directed (Asset);
- the legal entity, to which Project and Asset refer (Organization).

The references already present in PAS 1192-2:2013 are:

- the Employer Information Requirements (EIR), i.e., recognition requests for the client's individual order;
- the BIM Execution Plan (BEP), contractor's information scheme for the individual order, intervention, or contract;
- the Project Implementation Plan (PIP), the Master Information Delivery Plan (MIDP) and the Task Team Information Delivery Plans (TIDP), all operational order documents;
- the Project Information Model (PIM), order information model for the development stage.

The links to PAS 1192-3:2014 are instead:

- the Organization Information Requirements (OIR), recognition requests at Organization level (business strategy);
- the Asset Information Requirements (AIR), instruction requests at Asset level;
- the Asset Information Model (AIM), information model for the execution stage.

UNI EN ISO 19650-1:2018, for its part, incorporates the inputs from PAS 1192-2/3 and implements its structure. It consolidates the already present aspects of organization and property portfolio (OIR, AIR, AIM) and introduces new rules for the individual order. These include:

- the Project Information Requirements (PIR), information requests at Project level for the individual order;
- the Information Delivery Planning (IDP), an order delivery plan.

At the same time, by consolidating information aspects into general business direction factors, UNI EN ISO 19650 links data exchange rules to higher order management standards, such as:

- ISO 9000 family (quality) for the Organization level;
- ISO 55000 family (management and maintenance) for the Asset level;
- ISO 21500 family (project management) for the Project level.

The new regulatory structure covers not only the contract (Project: PIR, PIM, EIR, IDP, BEP, CDE), but also the entire cognitive process, from the care of the property portfolio (Asset: AIR, AIM) to the organization administration (OIR). The Italian UNI 11337 standard is a national annex of UNI EN ISO 19650 and therefore deals with defining international requirements of the latter for the Italian market, providing for an overall reorganization and updating. The UNI/TR 11337-2:2021 goes into more detail on these issues and is also the last part made available by the national standardization authority until Q1 of 2022.

1.3 HOW? A broader perspective on BIM

The migration from the conventional, design-based approach to a model-based methodology requires significant changes in both the internal workflows of expert teams and cross-cutting business processes. To avoid unduly disrupting the basic functioning of established pipelines, a gradual transition is preferred. Consequently, various technological levels of BIM implementation can be distinguished.

The most immediate differentiation contrasts “little” and “BIG BIM” [3]. The former describes the use of a specific platform [1] by a single stakeholder to achieve a defined goal. In most cases, the software is employed to create a building virtualization and derive drawings that fit into the conventional process. The model is not used across different software packages and is not handed over to other stakeholders. This implementation is, therefore, an insular solution within a design discipline, with all external communication taking place using drawings. Though the introduction of “little BIM” can offer efficiency improvements, the full potential of digital building information is still unexploited (Fig. 1. 5).

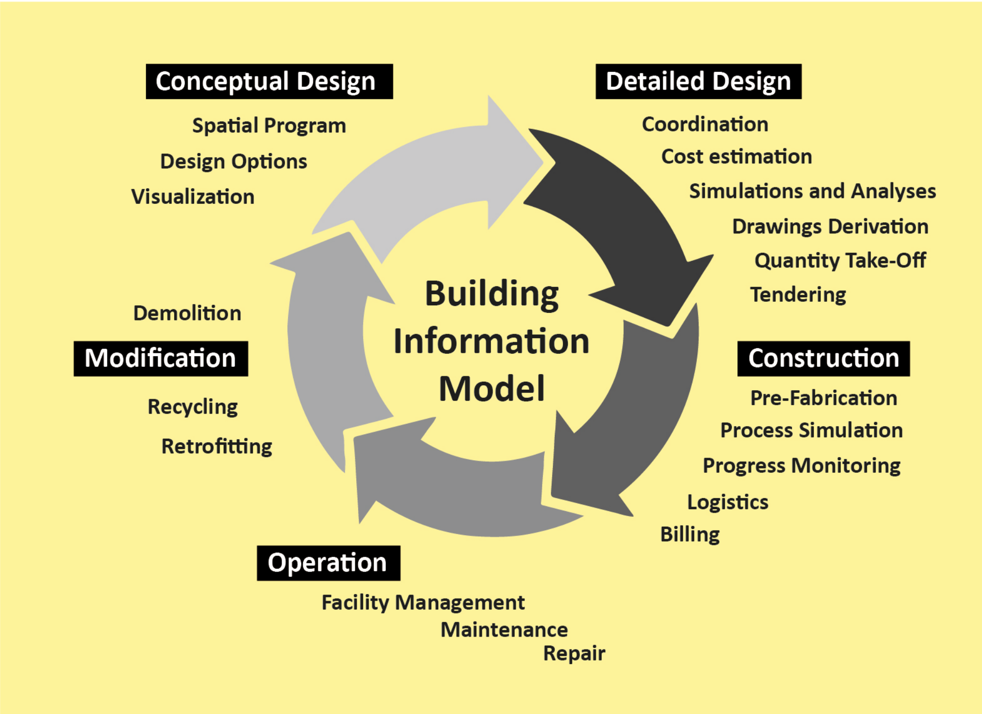

Fig. 1. 5. BIM model across the entire building life cycle (based on Borrman).

In counterpart, "BIG BIM" implies consistent model-based communications between all parties involved and across the entire life cycle of a structure. For the exchange of data and the coordination of the workflows, digital technologies such as model servers, databases or project platforms are comprehensively employed.

Next to the broader and deeper implementation of BIM we must consider the issue of using platforms and tools from only one supplier ("Closed BIM") or orienting to neutral data formats to allow exchange between products from providers ("Open BIM", Fig. 1. 6). Although some companies offer a wide range of software necessary for the design, construction and operation of built structures, there will always be a need to exchange data with other products that serve a specific purpose in the overall process. The variety of systems is usually a result of the many disciplines involved and the distribution of tasks between different stakeholders.

Despite recent progress, the exchange of BIM data using a standardized format still does not work perfectly, resulting in loss or misinterpretation. Both the definition of neutral formats and their correct implementation is a technically challenging task, but there are promising signs that the remaining problems will be solved very soon if software providers are serious in pursuing the goal. This depends strongly on how much market demand there is (e.g., from the public sector) for the implementation of "Open BIM".

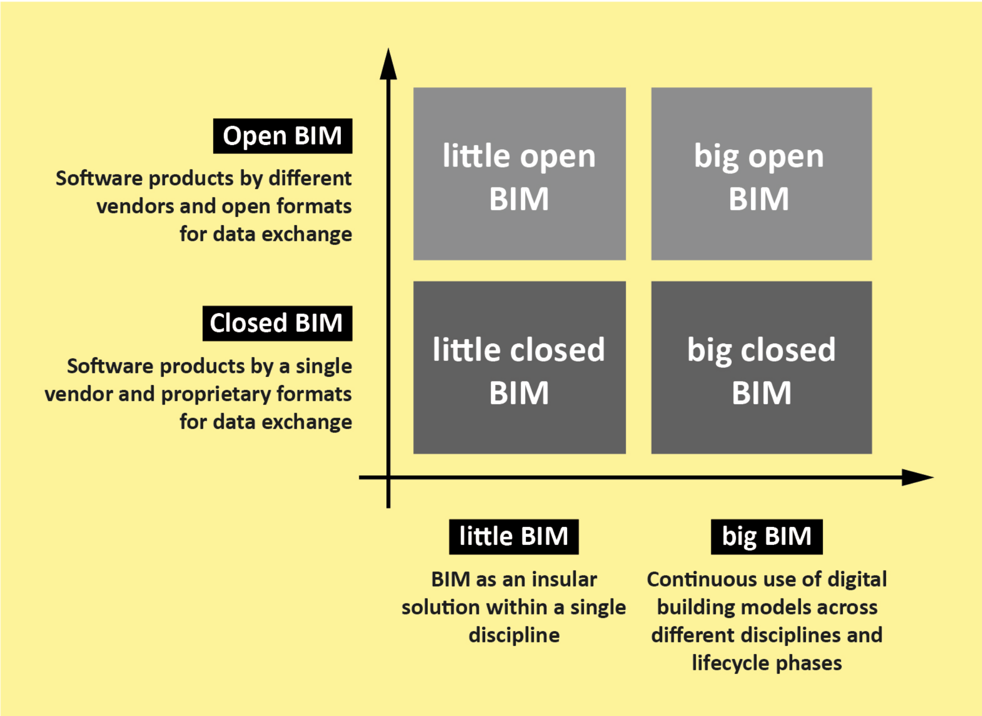

Fig. 1. 6. Levels and forms of application for BIM methodology (based on Liebich et al.).

The construction industry cannot make the transition to working procedures based on fully digitalised models - i.e., "BIG Open BIM" - in one go. Instead, a more appropriate approach is to introduce the new technology and accompanying changes into the processes step by step. To describe the solution, the UK BIM Task Group developed in 2008 the first BIM Maturity Model which sets out four discretized levels of deployment. Based on this, the UNI 11337-1:2017 standards proposed a new model of digital maturity in the construction process, articulated in five phases.

In Level 0 informative content is transferred through non-digital outputs (graphics, documents, multimedia), mainly on paper. They can be derived from digital outputs, which however are not contract information carriers. Level 1 (basic) involves exchange and delivery through digital outputs, collected in some cases in a core system, but the content is predominantly reproduced on paper. Level 2 (elementary) involves the use of BIM software to create graphical models, at least for the environmental and technical areas. In all other cases and for content that cannot be transferred in this way, many types of digital outputs are used, although paper remains the dominant medium. With Level 3 (advanced) the main objective becomes the correlation between graphical models and informative outputs in all their forms, with a prevalence of digital media for the reproduction of informative content. The employed tools are digital information sheets, a structured collection of data written in a set order. The correlation becomes the prerequisite for building an advanced digital project. In Level 4 (optimal) the transfer occurs through not only graphical but also documental and multimedia models, possibly accompanied by digital processing.

The complexity of these aims suggests the high level of challenge involved in this radical redefinition of the way data is managed, and how reductive it is to interpret the transition to BIM as simply the use of a new digital tool. A fundamental requirement for success is the consciousness that the main innovative value of this methodology lies in the possibility of structuring information coherently and not in the technical functionalities made available, however advanced.

Considering these assumptions, it is natural to move towards a broad vision of BIM, away from a fragmented and differentiated treatment of issues (BIM, Existing BIM, Historical/Heritage BIM), imagining a system made up of four interconnected elements:

- functional aspects;
- informational aspects;
- technical aspects;
- organizational and legal aspects.

If we imagine these four elements as nodes and the flows of information and definition previously introduced as arcs, we can represent the entire methodology as a graph and define a framework to be progressively enriched with new issues and themes deepened in this work (Fig. 1. 7).

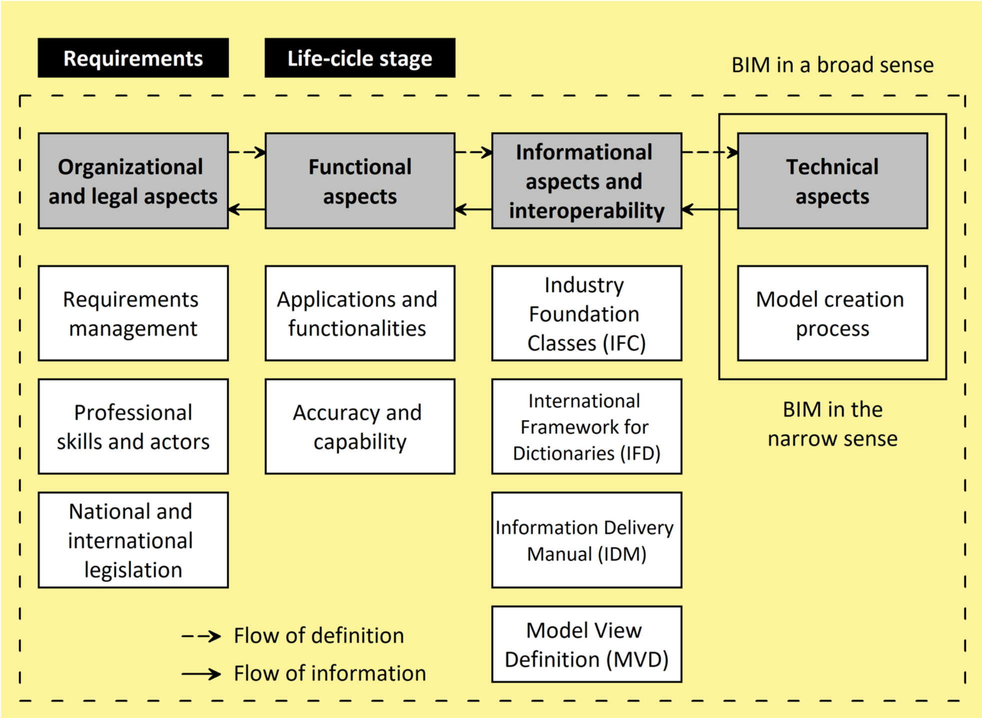

Fig. 1. 7. Relation between the different aspects of BIM (author's elaboration).

Functional aspects

Applications and functionalities
Due to the numerous engineering, construction, maintenance, and deconstruction services during the life cycle, the potential applications and functionalities of BIM in buildings and infrastructures are manifold.

Depending on stakeholder and project requirements, a BIM with architectural, construction, piping and electrical, structural, fabrication or monitoring performances could be necessary. This issue is inherent to BIM 'dimensions', an intuitive way to define the topics that come into play in digitizing the building process (Fig. 1. 8). If three dimensions are sufficient to fully outline the geometric attributes of an entity, there will necessarily be other descriptive modalities to touch aspects such as time and costs, which will be specifically detailed according to the type of contract.

The UNI 11337 standards also refer to a similar approach in parts 5 and 6, when they deal with the administration section and require you to specify:

- programming management modes (4D);
- economic management, with calculations, estimates and valuations (5D);

- modes of use, maintenance and decommissioning of the work (6D);
- management of social, economic, and environmental sustainability (7D).

In relation to geometric (3D) attributes, the graphical virtualization is not an end, but it contemplates the interaction of the various actors and disciplines involved. It is born therefore the necessity to handle the activity known like Model Checking, which can be formalized in two distinguished operations:

- the Code Checking, that is the verification of the adherence of the model to the planning and normative demands;
- the Clash Detection, that is the preventive analysis of the geometric conflicts (and not) present in the model.

The need to deal with timescales (4D), an aspect linked to management more than to building design, is not new and stems from the awareness of the limits of traditional methods (Gantt and Pert diagrams, etc.) for administrating the duration of a construction site or, generally, of a job order. In fact, data loss and ineffective communication between contractors and the authority are frequent.

The use of digital tools makes it possible to reduce and reorganize time in a way that is dynamic and open to analytical evaluation. The construction of a Work

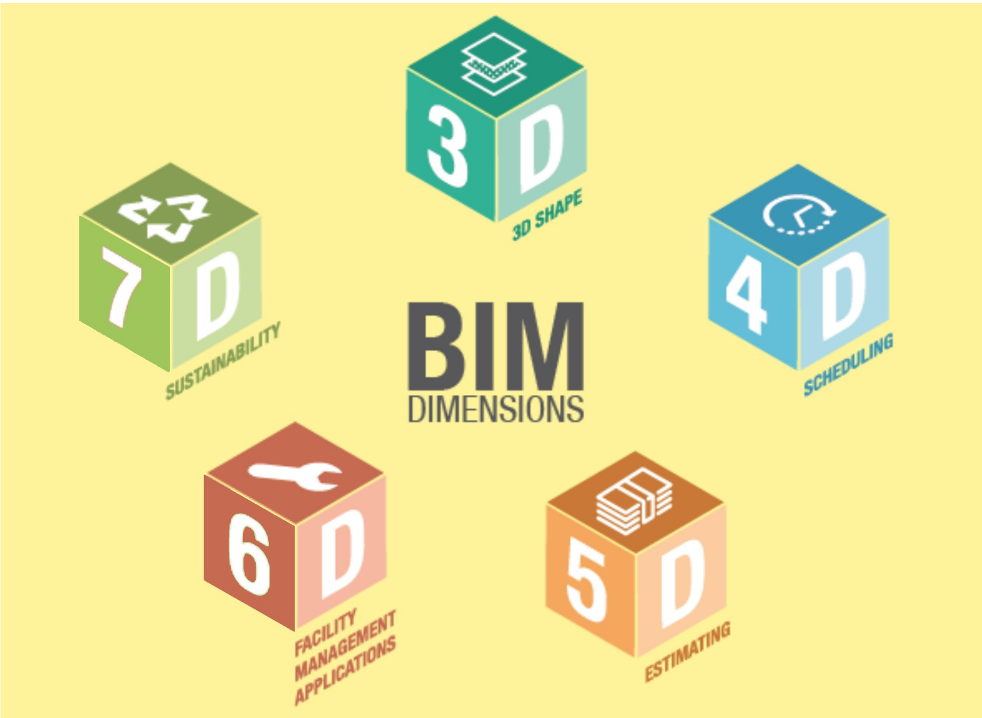

Fig. 1. 8. The seven ‘dimensions’, representing the main functionalities of a BIM model.

Breakdown Structure (WBS) allows the reasoned decomposition of a project into related elementary parts, from which it is possible to extrapolate and visualize the progress of the tasks.

Cost assessment (5D) has been under study for a long time, and there are well-structured workflows and IT tools that can meet a variety of needs. Certainly, we cannot speak of a 'dimension' that is free of errors. The key point of the methodology is the Quantity Take Off, that is the extraction of the measures from the project in order to define the demanded materials.

Despite this innovation, many questions still need to be answered. Are we sure that the engineer has all the necessary data to make a choice that is in line with the designer's requirements? Is it possible to concretize the 'dimensions' of time (4D) and cost (5D)? It is clear how the rethinking of processes, interactions, and tools can streamline content governance and link the different 'dimensions' throughout the building life cycle.

In terms of management (6D), a BIM model in its broadest sense must contemplate the transmission of the information database built around the graphical virtualization of an entity, so that products can be stored and shared. The latter do not close a process but simply move on to the next stage related to the operation of the work.

The aspect of sustainability (7D) is topical and aims to converge the exploitation of natural resources, the direction of interventions, and the orientation of technological development and institutional efforts toward a path that meets actual needs in a balanced way as well as those of the future.

To apply this concept to a work and then talking about supportable design is not easy, even more so doing it from the point of view of innovation. Is it the amount of technology (systems, automation, etc.) present in a building that contributes to its sustainability or is it the technic quality, intended as integration with the building - its properties and its elements - that makes it effective?

Probably, the adoption of a methodology that forces the programming of processes and opens the architectural fabric to a simpler management will allow making more performing the analytical operations today involved in the evaluation of the concept of sustainability of an asset.

Beyond 'dimensions', independent expert applications and functionalities are linked to BIM and use the underlying data to support, extend, calculate, or simulate specific business requirements (e.g., perform structural analysis). The results are reintegrated into the model or reported separately. Capabilities are based on process maps, which describe the logical flow of information and activities as well as the roles of stakeholders (ISO 29481-1:2016).

Although digital costs estimation, Quantity Take Off, data management and reporting tools are used in deconstruction industry, BIM functionalities of dismantling [4, 5], vulnerability and collapse analyses, emergency control, localization, or documentation of hazardous or contaminant materials [4, 6] or risk scenario planning [7] are rare in literature. In addition, other potential BIM functionalities are not yet addressed such as deconstruction design and progress monitoring, recycling and rubble management, auctions of secondary components and raw materials, recovery network logistics, tracking of hazardous elements or automatic reporting to authorities.

A reason might be the low participation of plant operators, retrofitters and deconstructors in the deployment of BIM capabilities. Another cause might result from standards, that define several properties and attributes to help maintenance processes [8], but only partly enable deconstruction and recycling features.

As described functionalities require accurate information on objects, relations and parameters, support and updating of contents in BIM remains a major challenge and area of research [9, 10]. Due to long lifetimes of buildings and infrastructure, recent investigation also addresses model evolutions, continuous management of temporal data [11] as well as the interoperability with developing BIM and expert software [9].

Accuracy and capability

BIM functionalities require a certain accuracy, information richness and actuality of the underlying data to fulfil their purposes [1, 12]. A frequently mentioned concept to describe completeness of contents for BIM objects is the Level of Development (LOD) [13]. LOD defines geometric and non-geometric attributes provided by a model component, often referenced to a specific moment, life cycle stage or to a contractual responsibility. To enable analysis or scheduling functionalities, the required LOD of objects' attributes and relations must be defined, such as durations, dependencies, or hierarchies. If CAD already highlighted that the concept of scale (of drawing) had long-lost much of its sense - excluding the printing phase of the tables (2D) -, the introduction of BIM and the shift from design to 3D virtualisation revealed the need to implement a new system for surveying data.

The LOD concept was therefore developed as a measure of the quantity and quality of the information supplied. Today the acronym is taken for granted, as well as the connection of the scale of the model's contents with physical elements. However, this has not always been the case and the actual acronym hides several interpretations (Table 1. 1). LOD was developed in the USA (BIM Forum LOD Specification) as Level of Detail with reference to objects (door, wall, pillar, etc.). The term Detail continued to strongly join the new system to the geometrical representation. For this reason, in 2013 it was decided in the USA to introduce the concept of Development, with the aim to overcome the direct connection with geometry in order to consolidate the notion of information quantity and solidity. A high or low LOD has variable information, but especially such information is binding depending on its evolution. The USA's LOD scale is measured in hundreds, from LOD 100 to LOD 500, where LOD 100 means that there are fewer

Table 1. 1. Correlation between LOD in different technical specifications.

LOD USA	LOD UK	LOD ITA
	LOD 1 - Preparation and Brief	**LOD A** - Oggetto Simbolico
LOD 100 - Concept	**LOD 2** - Concept	**LOD B** - Oggetto Generico
LOD 200 -Design Development	**LOD 3** - Developed Design	**LOD C** - Oggetto Definito
LOD 300 - Documentation	**LOD 4** - Technical Design	**LOD D** - Oggetto Dettagliato
LOD 350 - Construction	**LOD 5** - Construction	**LOD E** - Oggetto Specifico
LOD 400 - Construction	**LOD 6** - Handover	**LOD F** - Oggetto Eseguito
LOD 500 - Facilities	**LOD 7** - Maintenance	**LOD G** - Oggetto Aggiornato

and less consolidated data (these may change when moving to the next LOD and acquiring more in-depth contents), compared to LOD 200 and so on. However, also the USA LOD requires the need to measure both the graphical geometrical information and the alphanumeric ones. The BIM Forum Specification [13] is divided into Part I - Element Geometry, and Part II - Attribute Information, even if the division has never been formalized.

In addition, the UK system developed from the outset the concept of information scale: LOD, defined in PAS 1192-2:2013. In this case, though, LOD means Level of Definition, which is divided into Level of Detail (LOD), for the graphical-geometrical attributes and Level of Information (LOI), for the non-geometrical or alphanumerical ones. Furthermore, the letter D has three meanings between the UK and the USA: development, detail, definition. Moreover, in the UK system the LOD scale refers to the model in PAS 1192-2:2013, changing name depending on the project stages (Brief, Concept, etc.), as Level of Model Definition (LOmD). Since 2015, the UK LOD also pertain to objects in the NBS BIM Toolkit, with the more familiar measure in units (from 1 to 6).

To date, at least a dozen of LOD systems is counted worldwide, many of which use a scale in hundreds (LOD 100, 200, etc.) similar, but not identical, to that of the USA. In Italy, UNI 11337-4:2017, introduced a structured network of LOD, related to objects and measured in letters (from A to G) so as not to confuse the market (since it is a synthesis of the UK and USA experiences brought within national specificities, Table 1. 2). From the outset, LOD in the Italian standard becomes the acronym for Level of Development of Digital Objects, with a distinction between Level of development - Geometric Attributes (LOG) and Level of Development - Information Attributes (LOI), but the aspects characterizing the standard does not end here. In fact, the starting point is not the specification of objects, but rather the need to specify the goals of the stages and phases of each process. This approach is certainly interesting and original in the panorama of international technical standards, anticipating what was subsequently introduced by UNI EN ISO 19650.

Table 1. 2. General LOD scale from UNI 11337-4:2017.

LOD A	The entities are represented graphically by a system of geometric symbols or representation taken as reference without geometric constraints. The quantitative and qualitative characteristics are approximated.
LOD B	The entities are virtualized graphically as a generic geometric system or outline geometry. The quantitative and qualitative characteristics are approximated.
LOD C	The entities are virtualized graphically as a defined geometric system. It defines the quantitative and qualitative characteristics in a generic way and in accordance with the limits of the legislation in force and the technical reference standards applicable to a range of similar entities.
LOD D	The entities are virtualized graphically as a detailed geometric system. The quantitative and qualitative characteristics are specific to a range of similar products. This LOD defines the interface with other specific construction systems, including the approximated spaces for movement and maintenance.
LOD E	The entities are virtualized graphically as a specific geometric system. The qualitative and qualitative characteristics are specific to a single production system related to a defined product. It defines the details related to manufacture, assembly, and installation, including the specific spaces for movement and maintenance.
LOD F	The objects express the virtualization verified at the specific site of the production system implemented/built (as-built). The quantitative and qualitative characteristics are specific to the single production system of the laid or installed product. For each single product, it defines the management maintenance and/or repair and replacement work to be carried out throughout the life cycle of the work.
LOD G	The objects express the updated virtualization of the actual state of an entity at a specific time. It is a historical representation of the passage of the useful life of a specific production system updated with respect to that was originally implemented/built or installed. The qualitative and quantitative characteristics are specific to the life cycle of a previous state. It annotates each individual (and significant) management, maintenance and/or repair/replacement work carried out over time, and records the level of any degradation in progress.

Therefore, the models, objects, and outputs logically become instrumental in achieving the aims. In other words, the client is called upon to identify the content targets of each phase of the process in the Information Specification (in Italian regulations equivalent to the Employer Information Requirement (EIR) of the British PAS). From the uses of the model it follows, with logical consequentiality, the need to specify the LOD of each object constituting the virtualization.

For example, once the project reaches the authorization phase (to obtain opinions and permissions) the models must convey a quality and quantity of information such as to be able to satisfy the requirements of authorities and third parts responsible for issuing the specific approval documentation. Therefore, the LOD of the objects constituting these models must be adequate to grant the extraction of the required graphical outputs or quantities for the evaluation of the metric calculation or of urban planning indices, etc.

In order to allow a conscious use of data and information among the actors of the process, the standard introduces and defines the progress status and the approval one for models and outputs (UNI 11337-4:2017). They identify, respectively, the degree of operative advancement and the degree of formal reliability of the informative content. The interchange flow is described in detail, highlighting the evolution of the progress and approval statuses, and indicating the moments relating to verification and coordination, specified in part 5 of the standard.

With the publication of UNI EN ISO 19650, the LOD scheme that had established over the years, even if with some differences between countries and technical systems, has partly overturned by the introduction of Level of Information Need (LOIN). LODs define the gradualness of the contents set out in advance (LOD scales) to be referred to. LOINs, instead, open the data paradigm to a variability describable a priori because dependent on the specific needs of the moment (object, subject, phase, intervention, etc.) independent of each other, a concept already introduced in Italian regulation UNI 11337-4:2017 and deepened in the UNI EN 17412-1:2021.

Beyond LOD, several BIM assessment frameworks are under development, such as CMM6, CMMI, P-CMM, Object/Element Matrix or ISO/IEC 15504 (SPICE) [8]. As the latter generally plans the process rating, the Capability Maturity Model (CMM) is used in BIM contexts to evaluate if BIM projects or actions reach the desired grade of functionality. CMM assessment framework formulates minimum proficiencies and requirements of BIM model and process development with ten levels defined for categories: Spatial Capability, Roles/Disciplines, Data Richness, Delivery Method, Change Management or Maturity Assessment, Business Process, Information Accuracy, Life cycle Views, Graphical Information, Timeliness and Response as well as Interoperability and Industry Foundation Class Support.

For maintenance functionalities, the Construction Operations Building information exchange (COBie) standard defines a LOD for technical equipment, regarding type and location, make, model and serial numbers, tag, installation date, warranty, and scheduled maintenance provisions.

Professional associations try to define and harmonize related concepts and ratings measuring BIM’s data requirements and capabilities, yet there has not emerged a standard assessment framework of BIM for both new and existing buildings. Another relevant factor is that all systems used today mainly evaluate the completeness of informative contents against defined standards without considering their accuracy, both about geometric and non-geometric attributes.

Informational aspects and interoperability

Interoperability i.e., the capacity to exchange data between applications, allowing workflows to be standardized, is one of the founding principles of the BIM methodology. This is not a new concept and the need for dialogue among tools and platforms intended for specific purposes but belonging to the same production chain has always been a requirement; for example, just think of the emergence of the DXF format for transferring graphical data of vector type between instruments from distinct software houses.

The urgency of this need, however, becomes paramount in the case of BIM methodology, where the integration of different knowledge is the essence of innovation. The quality of the information to be exchanged goes far beyond the simple graphical data, as the use of objects allows the management and transfer of contents related to materials, quantities, costs, times, energy, and structural analyses, etc. The topic of information exchange has therefore been the subject of much attention and effort on the part of research bodies, associations of software producers and manufacturing, constituting a real technology, which has evolved as applications and their needs have changed.

The Industry Foundation Classes (IFC) data exchange format, developed for years by BuildingSMART International, seems to have established itself worldwide in the BIM field. The organization was founded in 1995 as a private consortium of 12 companies under the name Industry Alliance for Interoperability; in 1996 it became the International Alliance for Interoperability (IAI) and was transformed into a not-for-profit industry association and opened to all interested parties, and only in January 2008 did it take on its current name to better reflect its nature and purposes.

BuildingSMART's activity focuses on three standards:

- Data Model, with Industry Foundation Classes (IFC) defined in ISO 16739-1:2018;
- Data Dictionary, with International Framework for Dictionaries (IFD) structured in ISO/FDIS 12006-3;
- Processes, with Information delivery manual (IDM), developed in ISO 29481-1:2016, ISO 29481-2:2016 and ISO/FDIS 29481-3.

As already seen, IFC is an information interchange format. It is a structured data model, a classification and description system referring not only to the physical components of the building such as walls, doors, and floors or their attributes such as transmittances and masses (tangible quantities), but also to abstract concepts like amounts, costs, and time sequences of work. The IFC structure defines a single object-oriented model of the artefact, interoperable between all compliant applications; it is an open data format, public and independent of any software producer. There are multiple versions of it, which are obviously continually developed as users' needs emerge: the most widely used is the IFC 2×3, but IFC 4 has recently been released.

The IFD standard, subsequently also called Data Dictionary by BuildingSMART, is essentially an international vocabulary aimed at univocally defining terms and related meanings of entities, products, and processes in the construction world. While the IFC standard describes the objects (organisms and procedures), how

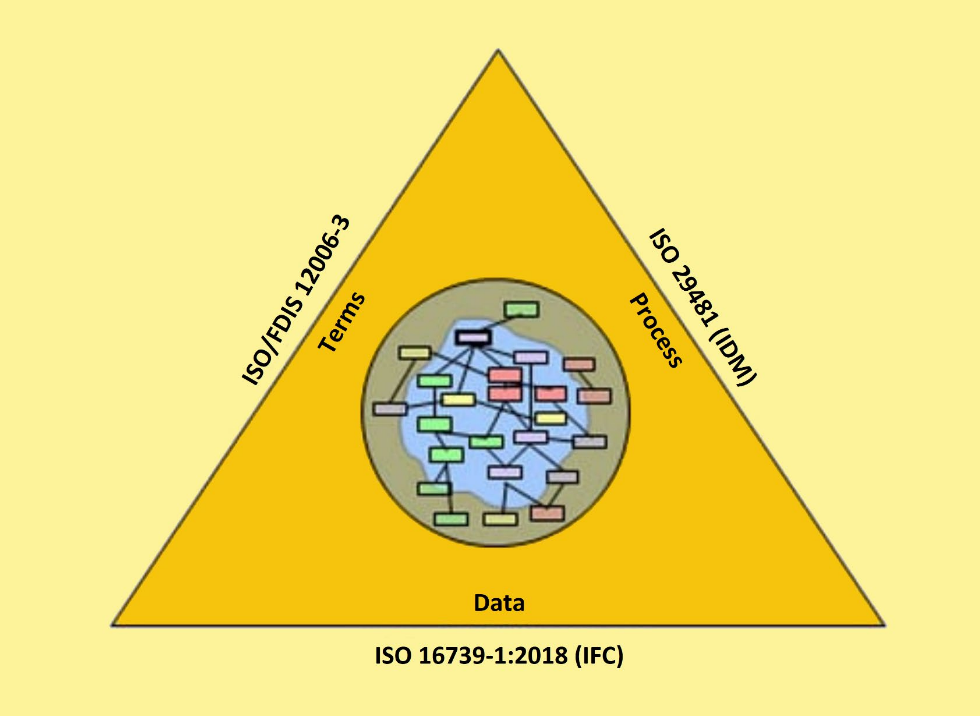

Fig. 1. 9. The three main standards on which BuildingSMART focuses.

they are connected and how the data is to be exchanged and stored, the IFD provides the dictionary with their specifications, properties etc. in order to enable a common understanding, which is essential for the smooth interchange flow.

Finally, the standard on the methodology for defining processes is called IDM. The need for this additional reference stems from the requirement to optimize the quality of communication between the different participants in the construction. In fact, the involvement of multiple professionals in a project, from the design and realization phases to the management ones, implies a large amount of information exchanged, sometimes not all of which is necessary in a certain step of the process or, on the other hand, not completely sufficient in the rest. In order to work efficiently, it is mandatory that all participants in the process know what and when the different types of information must be provided.

BuildingSMART has therefore developed a methodology for defining processes and related data flows throughout the life cycle of a construction, which can be used to document new or existing activities, describing the contents to be exchanged between parties. The outputs of the IDM standard may form the basis for defining in detail the specifications necessary for the development of software procedures; in order to make an information exchange manual operational, it must be supported by the IT applications. This is evidently because its main purpose is to ensure relevant data are communicated in such a way that they can be correctly interpreted by the target software.

Thus, the concept of Model View Definition (MVD) is born, linked to the peculiar IDM and describable as an Information Technology formalization of specifications and requirements identified in that manual. In other words, an MVD defines a subset of the IFC schema that needs to be implemented in software to satisfy the data exchange demand of a process or activity, described in the related IDM (Fig. 1. 10).

To support interoperability between hundreds of platforms and tools in different industries and regions of the world, IFC has been designed to be able to accommodate distinct configurations and levels of detail. For example, a wall can be represented as a simple line segment (or curve) between two points, or as a 3D entity for the sole purpose of three-dimensional visualization of the structure, or as a 3D building element with detailed information useful for its construction (individual pins, fittings, cabling, etc.) along with non-graphical contents such as costs, timeframes, etc. Thus, there is a need to clarify what data is required for each specific use. The operational importance of the availability of MVDs is evident at this point.

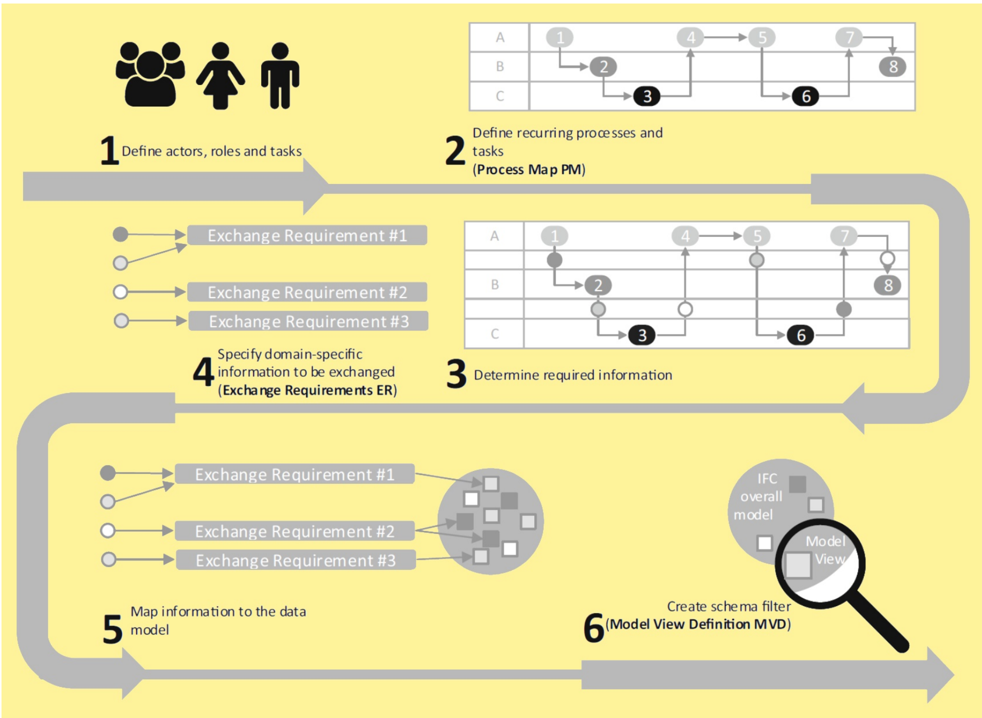

Fig. 1. 10. IDM/MVD method used for the IFC-based exchange (based on Beetz et al.).

Technical aspects
As the BIM modelling process is aimed at meeting the required functionality [14, 15], technical issues depend on the LOD/LOIN needed for the purpose. The creation of a BIM can be differentiated between new and existing constructions due to the various quality and availability of information and requirements. In the first case (I), the production of the as-planned BIM model is done in an interactive and iterative process with a commercial design software and allows the upgrade to an as-built BIM. Since many available buildings have rather insufficient documentation, either the pre-existing BIM is updated (II) [16] or a reverse engineering process [17, 18] is performed to describe the actual conditions of the structure (III) (Fig. 1. 11). To create an as-built BIM from scratch, the geometric and topological information of the building elements must be gathered, modelled, and supplemented by semantic attributes manually. If a reliable data capture technique could provide as-built BIM in reasonable time and cost [14, 19-21], existing buildings could benefit from the use of BIM e.g., in documentation, visualization or facility management. It is clear, in fact, that the three cases differ considerably in the potential modelling effort.

If the building information is insufficient for the required functionality, data capture or survey techniques are applied with an appropriate design. The LOD/LOIN determines all subsequent steps from technique selection to model creation, due to its great influence on the quality of the required data, its volume and processing effort. The use of digital acquisition solutions in the architectural field has now reached a wide diffusion, mainly due to the ability to detect with great precision, trueness, and without contact the artefacts and the possibility of generating information models useful for the phases of analysis, simulation, interpretation, and conservation. The wide diffusion of these techniques makes it increasingly clear that engineers need to know the basic principles for the operation of tools and methodologies on which the acquisition and processing are built.

The creation of reality-based three-dimensional reconstructions of artefacts or sites can be done using 3D data generated by active sensors (range-based like laser scanners, structured light projection instruments, radar, etc.) or 2D data from passive sensors (image-based like digital cameras) subsequently converted into 3D information with dedicated methods (photogrammetry, computer vision, etc.). The choice of the contents to be used or the survey technique to be employed is a function of the characterization of the surface to be detected, the accuracy and geometric detail required, the size of the object and its spatial location, experience, project costs, etc. For 'visible' assets, surveys are normally carried out with active or passive optical sensors while for 'invisible' structures (e.g., underground) techniques based on radar or geophysical systems are used.

Even if several solutions are available to generate realistic 3D reconstructions, characterized by a good metric quality and a detail consistent with the geometric features of the artefact, the best approach for surveying lies in the combination

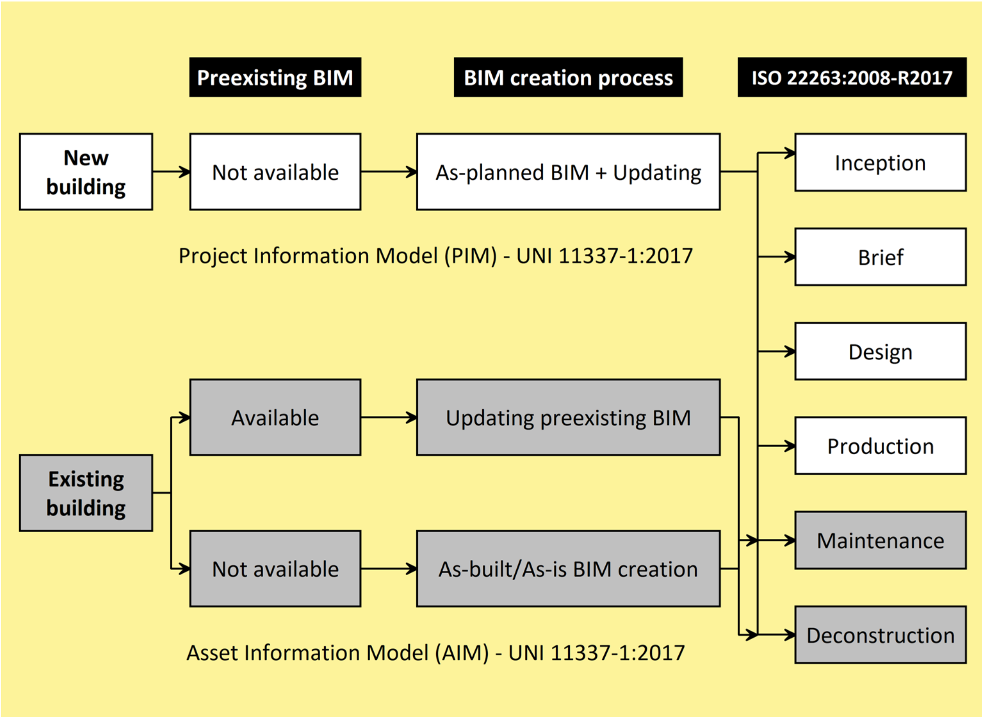

Fig. 1. 11. Creation process of a BIM model in new or existing buildings (author's elaboration).

of different tools and modelling techniques [22]. In fact, the use of only one 3D technology does not allow to date, in the case of large site detection, to reach yet a satisfactory result in all working conditions and in terms of geometric accuracy, portability, automatism, photorealism and low costs, with the same efficiency and flexibility. For this reason, data from passive and active sensors are very often integrated in order to exploit the full potential of each individual measurement technique.

Recent BIM investigation focused on capturing mainly geometric rather than semantic representations of buildings and feeding point clouds into software [17, 19, 21, 23-26]. But new developments intensely research of processes for automated BIM modelling from captured data and improvements in LOD/LOIN [21, 27, 28] to enhance application in available assets. In order to perform a comprehensive audit on existing buildings, the mentioned detection techniques might be combined with other methods of non-destructive testing to analyse materials and properties.

Possible solutions could include substance or texture-based recognition [21] and structure identification beyond surface through ground penetrating radars, radiography, attractive particle inspection, sonars, or electro-magnetic waves [25] or tags installed during retrofits.

As the functionality requirements determine the LOD/LOIN and thus the capture technique, they also influence the content volume, manipulation and the associated time and effort. Data processing is performed to enable the recognition of functionality-relevant BIM objects in previously captured building information, e.g., to detect installations or maintenance accessories; during its steps, image and range-based point clouds are registered, aligned, and integrated in the same reference system [27]. This is mostly done interactively, through defined coordinates or features detected as descriptors or tie points [27, 29]. Then, the product is cleaned of noise, irrelevant information, and clutter [22, 27] and often decimated to improve efficiency. Data captured by other techniques are handled according to their format, required functionality and object recognition method [30-32].

Applied to meet the specific purposes of maintaining or deconstructing complex structures, processing may exceed reasonable computation times due to increased LOD/LOIND, high volumes or limited capacity of devices. Further developments in the hardware and software performance and research into outsourcing to cloud servers could enable faster treatment.

The captured and processed building data is used to identify components and their characteristics relevant to required functionalities. The object recognition includes identification, extraction of relational and semantic information as well as treatment of concealments and remaining clutter [27]; methods and tools differ due to geometric complexity of the building, required LOD/LOIN, and applied capturing technique, content format, or processing time.

We can define three main approaches: data-driven, model-driven, and other recognition solutions. The first ones extract building information from captured data and can be differentiated into feature, shape, material-based and statistical matching methods. Model-driven approaches are rather developed on a predefined structure, such as topological relations or constraints and perform pairing of captured data through knowledge or contextual information. Other procedures include manual identification or tags. Some publications combine data and model-driven ones to overcome drawbacks of individual methods [33]. Coarse and mainly planar building components such as walls, ceilings, floors, doors, windows, and clutter are identified in small scenes of single or few rooms with recognition rates between 89 and 93% [33]. But nevertheless, research approaches try to further improve the latter values as well as handling data uncertainty through statistical (thresholds), contextual (semantic nets, relations) or interactive (machine learning) methods [17, 29, 33-36].

Modelling consists in the creation of BIM objects representing building components, including both geometric and non-geometric attributes and relationships. If the BIM is realized since a survey, the previous methods of data acquisition, processing, and recognition influence the quality of the virtualization, depending mainly on the technique used. In order to compare different approaches and their capabilities, the products could be assessed, for example, with respect to the accuracy of the survey and modelling [27, 37]. However, no standard BIM evaluation method has been established to quantify these aspects.

Basically, as-built BIM is done interactively in a time-consuming and error-prone process. In research, automated patterning or transformations of surfaces into volumetric, semantically rich entities are in an experimental phase, with variable results. [19, 21] Many reviewed publications cope with semi-automated modelling of building components with respect to their geometrical representations. However, they do not regard properties or semantic information yet [17, 19, 21-26, 35, 38, 39]. If non-geometric attributes like functional, relational, or economical details of existing buildings are integrated into BIM, it is done interactively or semi-automated [14, 21].

The high LOD/LOIN e.g., required for specific maintenance or deconstruction considerations is not compatible with current time and cost restrictions in the AEC/FM sector. Furthermore, object attributes and relationships relevant for these tasks are not yet widely modelled, partly due to undefined properties, unavailable libraries containing older structure components or unspecified LOD/LOIN. As skilled personnel and high efforts are necessary to model BIM of existing buildings, further research in automated capturing, processing, and modelling could reduce auditing cost and increase productivity in BIM-based maintenance and deconstruction activities.

Organizational and legal aspects

Flow of definition in digitised processes

The four basic elements of BIM (functional, informational, technical, organizational, and legal) are interconnected and can be interpreted as nodes of a graph. The arcs that connect them can be grouped into two fundamental paths: the flow of information, which moves from the technical aspects towards the organizational ones, and the flow of definition, which has the opposite orientation. As the names suggest, the first one defines the transfers of data coming from the model and the second one the instances that, after the processing of such contents, specify or update the virtualization itself.

The elements characterizing the flow of definition, dependent on the informational aspects, are covered in UNI 11337-5:2017. The management of the data requirements according to the Italian standard is done through the elaboration of the following documents, in analogy with the British norms and ISO 19650 (Fig. 1. 12):

- Information Specification (*CI*);
- Information management bid (*oGI*);
- Information management plan (*pGI*).

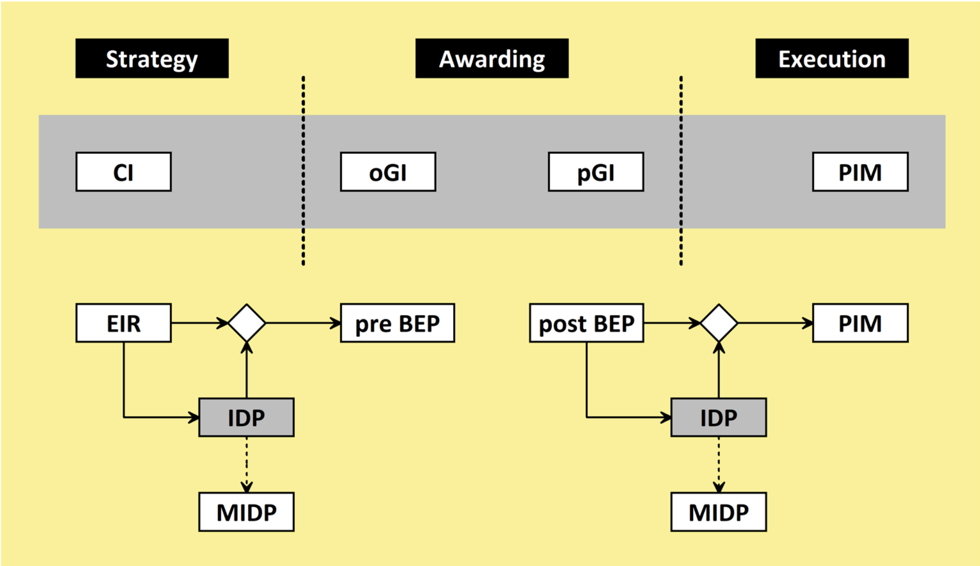

Fig. 1. 12. Correlation between contract information flows (based on ISO 19650 and UNI 11337).

In the *CI*, which is prepared by the client prior to the awarding procedure, all the information needs and requirements are specified. The parties interested in the granting of the contract shall draw up their own *oGI* in which they document their offer to meet the guideline of the customer. Before awarding the deal, the chosen contractor shall draft a *pGI*, in which the original proposal for data management shall be described in detail. This document must, of course, be composed in accordance with the binding principles of the offer and contain particulars of any subcontractors, in which case the rule makes the first-tier operator responsible for information management.

As regards the minimum contents of the *CI*, the standard lists the topics that must necessarily be covered, grouping them into two areas: the technical one (features of models, outputs and information sheets, data exchange formats, etc.) and the management one (interchange flow, verification, and coordination, 'dimensions', etc.). About the *oGI* and the *pGI*, the regulation does not provide a template. And this is obvious, as it is essentially made up of the requirements formulated in the *CI*.

The standard also deals with the management of information content, focusing on models, outputs, sheets; the aim is to guarantee the completeness, transmissibility, and congruence of the information they include. The *CI* and subsequent documents should define at least:

- number and type of single (disciplinary) models;
- single models to be aggregated;
- rules for interference management (Clash Detection);

- rules for regulatory checks (Code Checking);
- rules for managing information inconsistencies;
- roles and responsibilities of the subjects called upon to manage and solve the criticalities highlighted in the previous steps.

In virtualization management (Model Checking), the possibility of automating the association of models has always aroused great interest among operators. The standard defines three different levels of coordination:

- *LC1*, coordination of data and information within a single model;
- *LC2*, coordination between various individual models;
- *LC3*, coordination to be carried out between information content generated by graphical models and that not derived from them e.g., technical or calculation reports, CAD charts, etc.

The responsibility for these coordination activities lies with the person in charge of the specific model, in the case of *LC1*, while in the remaining two levels manager shall be identified in the *CI*.

For each stage and phase of the process (as defined in the UNI 11337-1:2017) there are moments of verification of the information conveyed. The standard provides for three levels:

- *LV1*, a formal internal audit, i.e., an inspection of the correct way in which content is produced, delivered, and managed in relation to the indications of the *CI* and the *pGI*;
- *LV2*, a substantial internal validation, aimed at ascertaining the readability, traceability, and consistency of the information contained in the various models. It is carried out by verifying, among other things, the achievement of the content evolution of the virtualizations and the LOD of the related objects, required in the specific phase according to what is prescribed in the *CI* and the *pGI*;
- *LV3*, a formal and substantial verification of the material deposited in the Data Sharing Environment, carried out by the client.

Part 5 of UNI 11337 also defines the general features of the Data Sharing Environment (*ACDat*, Fig. 1. 13), equivalent to the Common Data Environment (CDE) of the British regulations. This tool was introduced into Italian law by Article 23(13) of *D.Lgs. 50/2016* and subsequently by Article 2 of *D.M. 560/2017*, and consists of a digital environment for the organized collection and sharing of data relating to a work and structured in information concerning models and outputs, based on an IT infrastructure whose distribution is regulated by precise security systems for access, traceability and historical succession of the changes made to the informative content, preservation over time and relative accessibility of the data assets contained, definition of processing responsibilities and protection of intellectual prop-

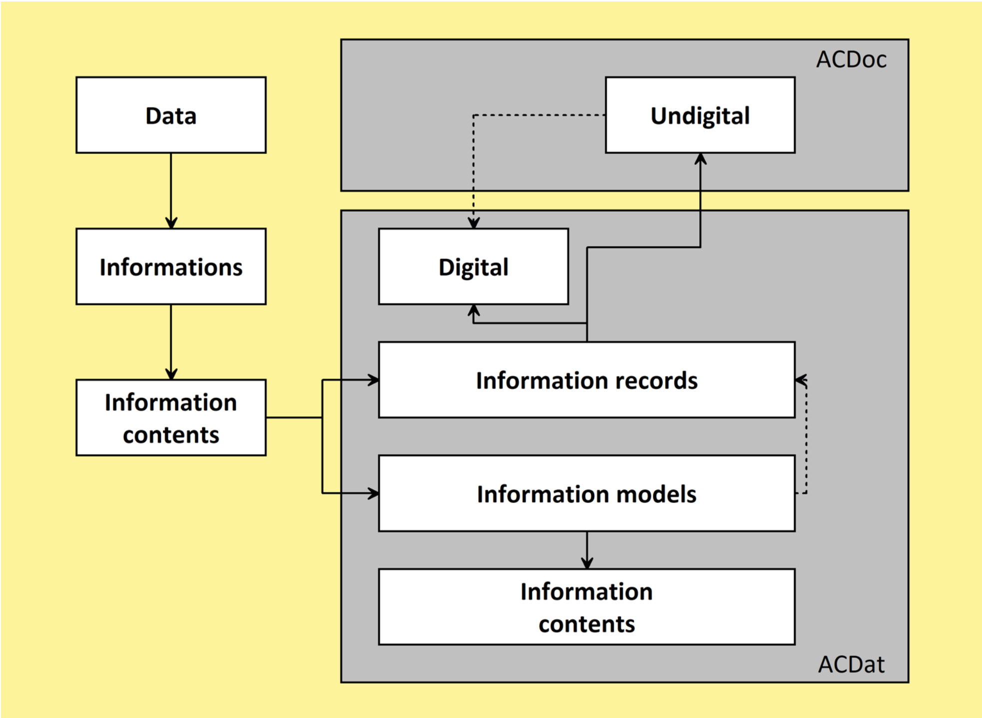

Fig. 1. 13. Content management in *ACDat* (based on UNI 11337-1:2017).

erty. The structure of the platform differs slightly from the British CDE and integrates seamlessly with some relevant aspects of UNI 11337, such as the coordination of models and the process, progress, approval, and verification of content.

Procedural guidelines

The purpose of part 6 of UNI 11337 is to provide procedural indications and a general outline of the *CI*, already introduced in its essential aspects in UNI 11337-5:2017. The example is obviously not exhaustive, since this document is to be drawn up by the client according to efficiency and effectiveness of the process and economic-financial aspects. The structure proposed by the standard is arranged in four parts:

- foreword;
- normative references;
- technical section;
- management section.

In the foreword, it is essential to indicate the stage of the construction process (UNI 11337-1:2017) in relation to which the task is being entrusted. No clarification is needed for the normative references. The technical section addresses issues such as hardware and software infrastructures, file formats and object entity specifications. Finally, the management section specifies the goals of the virtualization according to the process phases, the uses of the model related to the defined purposes, and the type and features of the graphical digital outputs.

The professional skills of the actors involved
UNI 11337-7:2017 defines the competences, knowledge, and skills for professional figures involved in information management and modelling. The aim is to specify which are the important profiles called upon to implement the interchange process and the proficiencies they must possess. These ones are described through a subdivision between tasks and peculiar activities, carried out according to the European Qualifications Framework (EQF). The requirements are intended to be used both to enable the assessment of informal and non-formal learning outcomes, and for the conformity evaluation of competences.

The standard identifies four distinct professions as key figures for the direction of a BIM process, thus introducing a diversification with the most widespread international practices. These positions are:

- advanced information management and modelling operator (BIM Specialist);
- coordinator of order information flows (BIM Coordinator);
- supervisor of digitized processes (BIM Manager);
- administrator of the Data Sharing Environment (CDE Manager).

For each profession, the regulation at first describes their specific tasks and activities in the interchange flow, also related to the organizations within which they are called to work. Once these responsibilities have been identified, the training content is then specified. The requirements are provided in terms of knowledge, skills, and competences, in accordance with the EQF. and reported in the form of schematic tables for easy reference:

- knowledge, result of the assimilation of information through learning;
- skill, ability to apply knowledge to complete tasks and solve problems;
- competence, demonstrated ability to use knowledge, skills and personal capabilities in work or study situations and in professional and personal development.

The standard does not go into detail about the level of such knowledge, skills, and competences, but it does identify the thematic areas around which the BIM Manager, the BIM Coordinator, the BIM Specialist and the CDE Manager must be able to operate.

BIM in Italian legislation
The legislation regulating BIM, or more correctly the specific electronic modelling methods and tools for construction and infrastructure, was introduced into the Italian legal system with Article 23 of *D.Lgs. 50/2016* (*Decreto Legislativo*, a legal

instrument) and, subsequently, detailed with *D.M. 560/2017* (*Decreto Ministeriale*, an administrative document), implementing the above-mentioned article. This discipline is in line with the new EU-derived rules, in the area of transparency and simplification of works award procedures, but also related to the issues of quality and innovation in the public contracts sector.

Starting from the need to enhance the design phase through the progressive use of specific electronic methods and tools, such as those of computer-based and information modelling for buildings and infrastructures, Article 23(13) of the *D.Lgs. 50/2016* codifies for the first time the possibility for contracting authorities to require the use of the BIM methodology. The article identifies, among other things:

- the characteristics that the specific electronic tools must possess; they use interoperable platforms based on open and non-proprietary file formats, with the obvious aim of not limiting competition among technology providers;
- the presence in the contracting stations of adequately trained staff, as a precondition for the use of electronic methods and tools.

The *D.M. 560/2017* defines the procedures and timescales for the gradual introduction of the compulsory use of IT solutions for public works, and it also identifies their scope of application; it is specified that their use extends to all phases of a project, from planning to management, including verification activities.

1.4 Setting the research within the proposed framework

The effort made to frame the pivotal aspects of the methodology is not only intended to serve as a tool for the critical analysis of the state of the art or as a schematic guide to the BIM approach. Its primary purpose is to encourage the systematisation of all the experiences and applications conducted during the writing of the thesis, to contextualise both the needs emerging from the literature review and the solutions proposed downstream of our research.

The presented work is developed along two paths. The first is related to the technical aspects of BIM applied to existing constructions. The main purpose is to formalize a procedural pipeline for reverse engineering implementations, especially with Scan-to-BIM techniques. Although the literature is rich in contributions analysing this topic, an organic treatment is lacking and there are many punctual experiences, related to the contingencies of the case study. Instead, our approach aims to generalize the results of applications and contribute to the outline of a best practice for the management of data derived from digital surveying. The proposed solutions attempt to foresee possible scenarios and offer valid alternatives to ensure a holistic treatment of the methodology. The structured organisation of models and outputs is not simply the product of factors emerging from the case study investigation, adapting to a wide range of situations without neglecting the requirements of current legislation and technical regulations.

There is also no lack of in-depth examinations on the processes of integrating survey data, mainly oriented towards low-level solutions, which are still not very widespread and therefore susceptible to refinement, contextualizing the conclusions with respect to design requirements. More in detail, structured point clouds of outdoor areas (single scans), derived from the TLS survey, are used, after frame orientation, to optimize the depth maps needed to generate the photogrammetric dense model. To date, there is no commercial software that allows this to be done automatically. Consequently, we introduce a script in Python that makes it possible to locate the scans in a photogrammetric project while preserving the information from the TLS registration.

Downstream of the acquisitions and their processing, we devoted ourselves to object recognition as a preparatory and support phase for the semantic classification. Here again, the aim is to propose a cataloguing system that is flexible and compatible with building regulations. In detail, we cross-reference data from the digital survey with data from other sources, almost always in paper form, to interactively identify the stratigraphic units of the structure under investigation. This information becomes the basis for describing the relationships between the digital objects that make up the BIM model. Unfortunately, there is no codified protocol to perform this operation, so we thoroughly analyse the sector's technical regulations to construct an appropriate classification system for existing buildings.

The second path of research focuses on the topics of data reliability and accuracy. The possibility of updating and reusing a model depends on precisely these two factors and, despite this, there is a lack of a unified framework to solve this critical issue. As far as the first topic is concerned, valid solutions emerge from the literature, but they struggle to establish themselves because they are not well integrated within the tools outlined by the technical standards. For this reason, our proposal for assessing reliability does not introduce any further novelties, but aims to seek out solutions already used in parametric modelling or related fields, reforming them if necessary and lightening the notional load on technicians, who could make use of tools they know and master.

The most interesting aspect for the purposes of an in-depth examination of reliability is represented by the verification levels which, together with the other points mentioned in the UNI 11337 standards, outlines the interchange flow. If we want to refer to the construction of the general architectural model for the case study, we are interested in level 1 of formal internal verification which follows the elaboration, and level 2 of substantial verification which follows the sharing and concerns the link with other models. We intend to take advantage of this framework to include our proposal, modifying level 1 which is no longer just formal but substantial for the individual virtualization and is aimed at ascertaining the readability, traceability, and consistency of the information.

Having clarified when to carry out the verification, it remains to define how to quantify reliability of the individual objects that make up the model. Once again, we use a tool that is already present in the Italian regulations: the levels of knowledge, which measure the degree of learning about a facility, achieved in relation to structural analysis methods, economic resources, and time available.

Turning to the subject of accuracy, the main proposals focus on the survey phases, presenting for modelling solutions that are either expeditious or in any case tied to the plug-ins of commercial software platforms. Alternatively, we suggest differentiated frameworks for survey operations and source-based virtualization, focused on statistical data processing and implementable in any workflow, without worrying about the specificities of the software used. In detail, we differentiate proposals according to the characteristics of the site, survey tools and techniques, project requirements and economic availability, in an inductive process that, starting from our experiences and their criticalities, pursues the objective of complete coverage of the subject.

Finally, the choice of the case study is not random. The building block analysed, located in the historic centre of a municipality in the province of Salerno, stands out for its stratigraphic complexity and articulated relationship with the surrounding urban spaces. These elements, although strongly characterizing, fully reflect the qualities of many centres in Campania, produced by centuries-old stratifications. Moreover, they present a wide range of criticalities, both for the surveying and modelling phases, which allow us identifying and field-testing potentially the best solutions for the specificities of the case, contributing to enriching the range of experiences necessary to generalize the results of the research.

1.5 Remarks and conclusions

The aspects discussed so far present a brief state of the art of the implementation and research of building information models in new and existing constructions, with a focus on the phases of the interchange process. Despite the increasing use of BIM, the application to operative assets is still limited. However, research approaches are intensifying to extend the methodology in this direction and to capture and integrate data from structures.

Although on the one hand, the implementation of BIM in both new and existing buildings induces profound changes in processes and interchange flows, on the other hand it accrues considerable benefits (Fig. 1. 14). The potential functionalities of BIM in advanced phases of the life cycle are numerous. Evaluation of alternatives and optimizations seem promising to improve project management and risk mitigation or to limit the cost and duration of FM or deconstruction actions, for example in complex structures or infrastructures. On-site progress monitoring, measurements and tracking through cloud computing describe potential future trends of automated acquisition and transformation of building information in BIM. Other important FM

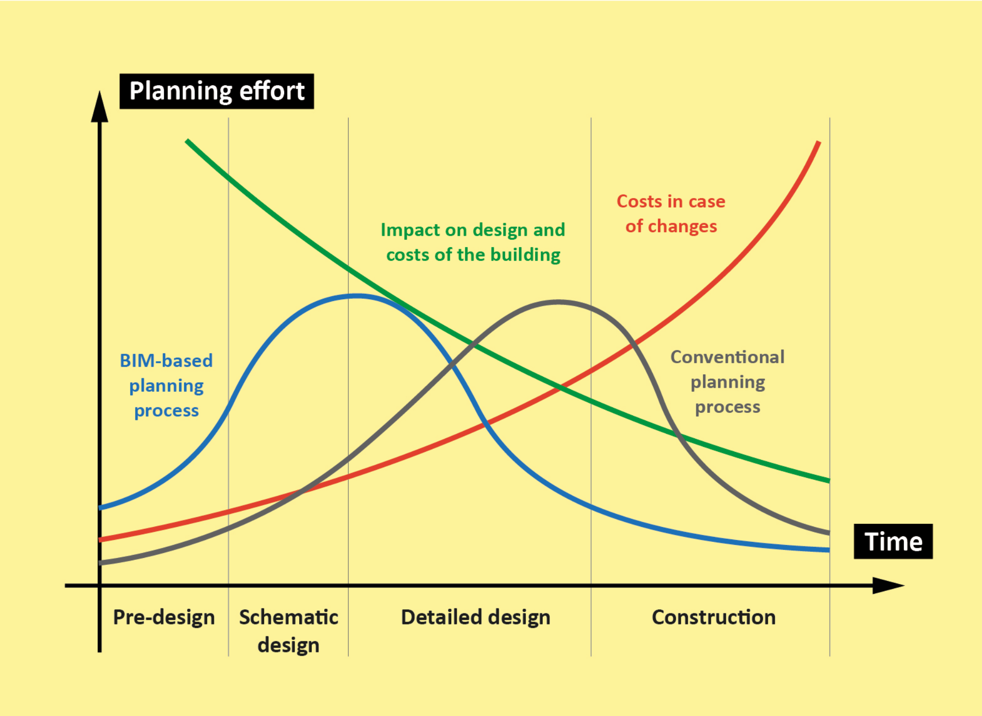

Fig. 1. 14. Comparison of planning effort and design decision (based on MacLeamy).

and deconstruction requirements such as cause-effect and deterioration modelling, diversion description or uncertainties are still rarely considered. To implement these functionalities, a structured and integrated data repository on building information like BIM could be beneficial for authorities, developers, or professionals.

The topics covered reveal that the main challenges and research areas are (I) automating data capture and creating BIM from survey outputs, (II) updating and maintaining contents in BIM, and (III) managing and modelling uncertain parameters, objects, and relationships occurring in existing assets. Integrated data capture solutions seek to overcome the lack of building information at low cost. Less dominant challenges are the different quality ratings of BIM models, the undefined LOD for some functionalities, the interoperability between BIM virtualizations of distinct generations, and the properties of objects and processes related to actual design needs.

The adaptation of legal and organizational frameworks on BIM differs from country to country. Progressive AEC/FM industries have driven the reform of the national regulations and implemented new collaborative processes through BIM, mainly for new buildings and not for existing ones. Organizational and legal issues seem to be important levers to influence the diffusion of BIM.

Fast developments of BIM and the release of standards such as IFC are promising for future automation and alignment of BIM with AEC/FM processes and efficient resource management through BIM in new and existing buildings. Long-time trends like the increased digitalization, growing built fabric stocks and sustainability requirements, as well as emerging technologies like cloud computing and semantic web will stimulate and extend BIM implementation in existing buildings.

The issues treated so far certainly cannot summarize the complexity of the subject in an exhaustive manner, but are intended to construct a framework within which to locate the applications and experiments described in the following chapters. An approach of this type applied to the BIM methodology, in both a multidisciplinary and interdisciplinary manner, can certainly simplify the understanding of the crucial problems and lay the foundations for a systematic treatment aimed at encouraging the diffusion of this type of modelling.

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2 Documenting built heritage with BIM methodology

2.1 The demand framework of Italian cities

The characterization of existing assets is a huge issue since the emergence of Building Information Modelling (BIM) in Architecture, Engineering and Construction (AEC) industry. Volk et al. [1] highlight the fact that despite well-established BIM processes for new structures, most of existing buildings is not maintained, refurbished, or deconstructed with BIM yet. This is because the creation of such a model can be completely different for the two possible applications (Fig. 1). In the first case, the purpose is to provide a product that is articulated in the distinct phases of the building life cycle (ISO 22263:2008-R2017), from inception to demolition (I). As the implementation of such models is not complete, isolated solutions, designed for a specific purpose, are too often employed. For existing buildings, depending on the availability of previously developed BIMs, the repository can be updated (II) [2] or re-created (III). In Italy, structures from the 1970s account for more than 60% of all constructions and are mainly without documentation in digital format [3]. Therefore, in practice, complex and costly reverse engineering processes (III) are almost always used to retrieve the necessary information [4] (Fig. 2. 1).

The first efforts and applications on BIM were directed towards meeting the modelling needs of new buildings, adapting to the virtualization of easily standardized objects. Consequently, tools and platforms were also developed following this trend. Technicians involved in documenting what is built, which by nature is made up of unique and non-repeatable elements, are therefore forced to adapt their workflows to the available tools. The public debate on BIM for existing constructions is often confusing and on occasions lacks a clear vision on end objectives. Many applications relate to historical buildings of great value. This is certainly not an anomaly, considering that Italy, as of November 2021, is the first country in terms of UNESCO sites (58, 45 cultural, 5 natural and 8 mixed), ranking ahead of China (56), Germany (51), Spain (49) and France (49). These places, thanks also to their ability to centralize attention in both academic and non-academic spheres, have become a benchmark for a new methodology such as BIM.

Since the introduction and formalisation of Historic Building Information Modelling (HBIM) by Murphy et al., there have been many valid and sometimes pioneering applications, such as Architectural Information Modelling (AIM) developed by Pauwels et al. [5], the NUBES project implemented by Livio De Luca's research group [6, 7] and proposals presented by Attar et al. [8] Fai et al. [9], Arayici [10] and Boeykens et al. [11]. At other times the results were less valid, with BIM virtualizations used as an alternative means survey data representation, showing unsupervised modelling and little interest in functional and informational aspects. It is suggested that a pure focus on HBIM will put it into a niche and delay its take-up for most of consolidated urban fabric.

In order to help develop a framework for end-user-directed BIM for built assets, it may be useful to take a closer look at the subject by dividing it into two areas. Existing Building Information Modelling (EBIM) contains the basics needed to maintain and operate a construction, including data on the fabric and services, and an

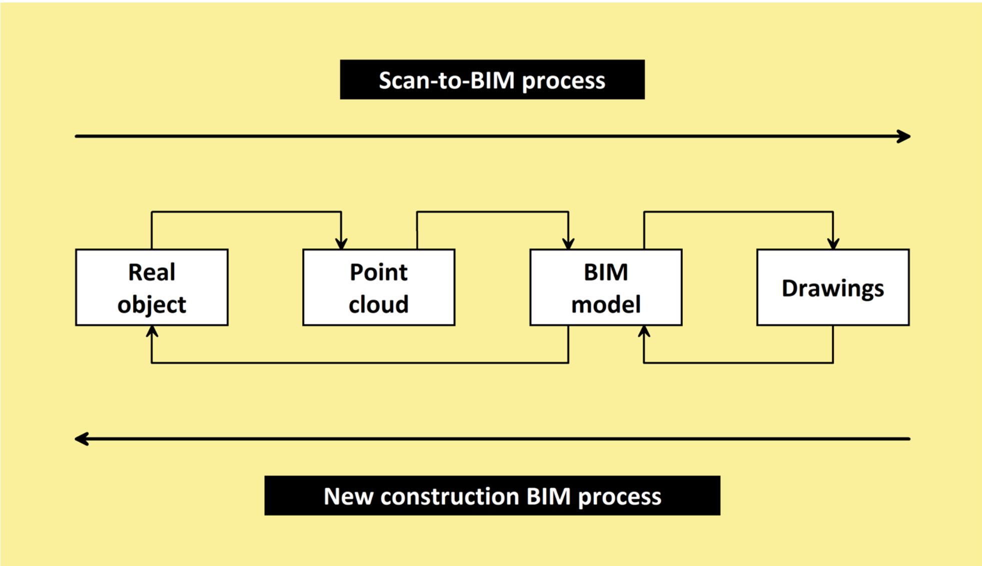

Fig. 2. 1. Direct (down) and reverse (up) engineering process (author's elaboration).

HBIM is an additional layer. The latter would also address historical and heritage information, significance values, conservation policies and perhaps a much more enhanced form of digitization, but this is related to the overall objective. EBIM and HBIM are ultimately about managing and maintaining properly and efficiently, and the specific designation of models depends on whether the buildings have any heritage value or not. Ideally, E/HBIM should also be suitable for energy and sustainability along with refurbishment and retrofit, but this concerns the extent and quality of the data within the model. Most importantly, the latter should permit the continuous enhancement of content input.

2.2 Road to E/HBIM

The construction of a BIM model, especially in relation to the advanced phases of a building's life cycle, is an operation that requires a certain investment, both in terms of time and financial resources. This raises whether it is worth it, and the first thing to explore is why we need it. When it comes to projects involving major improvements and renovations, we might be able to justify the additional costs, which depend, for example, on digital surveying and the production of a 3D model. However, most buildings will not go through such major improvements and refurbishments, and you must ask if there is any value in developing an EBIM for them. The *D.M. 560/2017*, in fact, introduces the compulsory use of digital tools only for public works while a large portion of the existing fabric, devoid of historical and cultural value, belongs to private individuals.

Most of the buildings in Homogeneous Territorial Zones (*ZTO*) *A* and *B* do not have CAD drawings or perhaps even paper documents. If a BIM model is to be produced, its quality and characteristics will need to be calibrated in relation to the specific objectives. For example, its use in the execution stage, i.e., in the maintenance and management phases, might justify the use of expensive digital survey tools. Otherwise, 2D drawings accompanied by good photographic documentation may suffice. Alternatively, there are less resource and time intensive solutions to produce a non-BIM oriented 3D model [12].

Regardless of these initial considerations, the advantages of using BIM are manifold: it can help to plan space utilization, schedule preventive conservation, organize reactive maintenance, standardize facilities, streamline processes, and align them with the service requirements of occupants and budgets. There are also benefits for coordinators of interchange flows, such as reducing the risk and uncertainty of interpreting, sharing, and integrating data. As for occupants, their satisfaction is increased through faster resolution of unscheduled work orders, improving communication between tenants, and building maintenance staff.

It is therefore possible to consider that these are real benefits brought about by what, in the context of this discussion, is EBIM. In summary, the tool should allow the following:

- planning and management;
- defining maintenance methods, materials, and components;
- mapping building services locations;
- governing energy use;
- sharing work specifications.

Analysis of the implemented applications shows, however, that we are still far from such a level of informatization. In fact, research on building management practices (especially for energy efficiency, concerning the state bonuses to revive the sector after the COVID-19 emergency) suggests that relatively few companies have fully coordinated computerized property management systems and some have no IT solution at all, other than monitoring by compiling information on spreadsheets. EBIM/HBIM developed in an appropriate form would undoubtedly help to improve property management (Table 2. 1).

To these potentials, we must add those related to historical assets, in order to take a further step towards an HBIM that also guarantees:

- documentation of the building over time;
- outlining of the different construction phases [13] [14];
- supervision of the required competencies.

Such BIMs should include details of what is necessary to manage and operate structures properly, and this should be derived from acknowledged best practice guidance. Many may argue that existing buildings do not require EBIM or HBIM and as they are adequately cared for without such a tool to handle and coordinate information. Others would argue that a big chunk of assets is not managed and maintained properly. This may be due to a lack of knowledge and expertise or a deficiency of resources and, more commonly, to being reliant upon third parties who do not have the most suitable skills [12].

The implementation of BIM will not automatically save buildings from disrepair and neglect, but it would mean using the most appropriate knowledge and resources to ensure that what is done is achieved properly, provided it is the right type of BIM, developed with apt expertise and competency. These thoughts support the idea of aiming at a methodical and structured treatment of the BIM

Table 2. 1. Major BIM functionalities for existing buildings (based on Volk et al.).

Clash detection	Spatial validation	Construction progress	Cash flow
Cost calculation	Daylight simulation	Deconstruction	Quality control
Defect detection	Documentation	Management	Monitoring
Energy analysis	Thermal analysis	Retrofit	Refurbishment
Scheduling	Structural analysis	Safety	Emergency

which, if not controlled and contextualized, would not only fail to guarantee the desired results but would further increase the disorder in the already vast and articulated panorama of property management.

2.3 The value of knowledge and case study analysis

As repeatedly stated, BIM is not necessarily the panacea to the coordination problems of the building industry information process, but it can become a valuable tool, especially for the execution stage of existing structures. Obviously, its implementation has a cost and it requires training of those involved to guarantee the desired results. It is therefore necessary to ask whether the benefits produced by the methodology are such that they justify the expenditure, especially in the private sector.

An exhaustive assessment can only be carried out based on a complete analysis of the case study, defining its characteristics, state of conservation, possible need for maintenance and intervention strategies. The object selected as a test bed for the proposed activities falls within the municipality of *Siano*, located in the northwestern area of the province of *Salerno*. It is a built lot at the crossroads between *Via Marconi*, in the historic core of the town, and *Vicolo Capuano* (Fig. 2. 2, Fig. 2. 3). The features of the complex formal structure, depending on its relationship with the site, the urban space, and the lot itself, allow it to be traced back to the block type. The building is morphologically and structurally compact, with three free sides and a small open space, off-centre and connected to a minor private road, which provides access to the upper floors.

From a plano-altimetrical point of view, the block is the result of successive transformations and mergers since the end of the 19th century, presenting a particular composition with mezzanines and heterogeneity in terms of structural typology. We can identify three levels above ground, completed by a fourth interposed between the first and second floors, and two basements, accessible from the mentioned decentralized open space.

There is also heterogeneity from a structural point of view. Vertical elements are mainly constructed of bonded natural stone masonry. More specifically, it is yellow Neapolitan tuff, a rather incoherent rock of pyroclastic nature, formed by the compaction and cementing of volcanic materials of explosive origin. This masonry is present both in the form of rough stones with mortar, in relation to the 19th-century core, and in the form of hewed elements with mortar, for the extensions carried out during the 20th century. The building renovation of the early 21st century introduced volumes with a reinforced concrete frame structure cast in situ. The horizontal elements, on the other hand, consist of mixed cast-in-place concrete and brick slabs, except for a single floor made of steel and brick stringers. Lastly, the cover is made up of a pitched roof, also in brick and concrete.

From an urbanistic point of view, the lot falls, for the built-up part, in the *ZTO A2*, with buildings and complexes that do not present characteristics of relevance

Fig. 2. 2. Mapping the area of interest on satellite images (based on Google Earth Pro image).

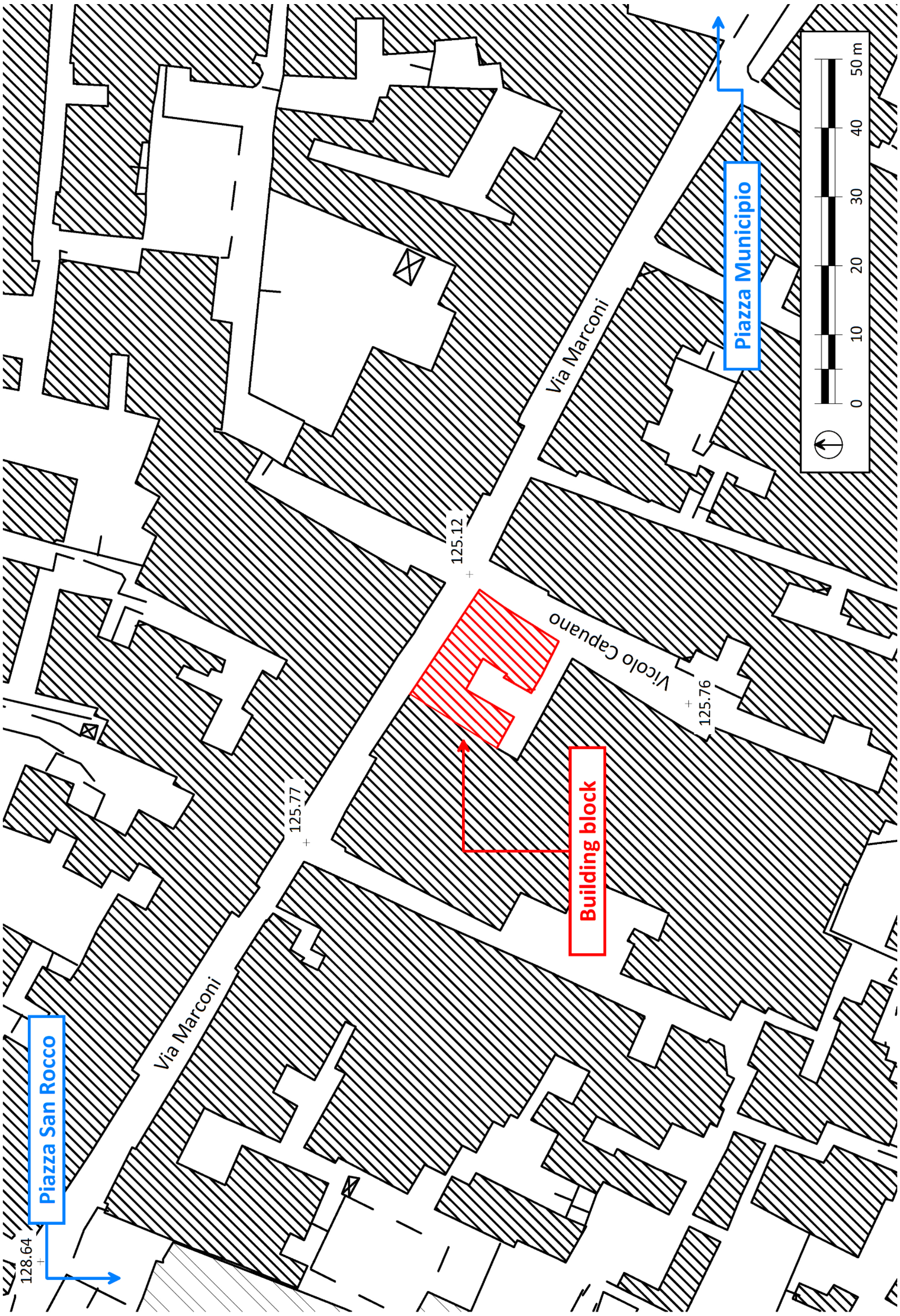

Fig. 2. 3. Mapping the area of interest on aerial photogrammetry (author's elaboration).

but constitute the prevalence of the consolidated fabric. The open areas, on the other hand, fall within *ZTO A3* of the pertinences.

The information collected from a compositional, structural, and urban planning point of view is a prerequisite for drawing up the client's requirements and formalising his requests, which will be included in the *CI* and will start the process of building the BIM model.

2.4 Requirement definition

The summary description of the structure and its parts flows into the introduction of the *CI*, a contractual document through which the client outlines its information needs in relation to the budget [15]. The next step is to define the type of intervention. In this specific case, the owners are interested in learning more about his property for several reasons. Firstly, the building has undergone many transformations over the years, which have not always been fully documented. It is therefore necessary to verify that the integration of the various interventions has been properly taken care of and that the structural elements are not affected by problems. The same applies to the energy aspects. An appropriate Asset Information Model can support a simulation of the power behaviour of the building in order to highlight possible criticalities.

It is almost superfluous to recall that the contents of the *CI* must comply with the legislative and regulatory references already mentioned and discussed in the previous chapter, as well as those relating to construction, town planning and safety. Instead, we need to pay more attention to the management part, which starts with the definition of the virtualization goals with respect to the process phases. For the case study, a general architectural model is needed for the execution stage with such a Level of Development as to reveal structural or energy weaknesses requiring maintenance (ordinary or extraordinary) or building renovation. This results in the possible employments of the model, i.e., the documentation of all internal and external spaces of the structure.

From the purposes and uses of the model come the digital outputs. A central issue, however, is the specification of Levels of Development for virtual objects. Considering the Italian UNI 11337-4:2017 regulation, the client must indicate the reference system chosen for the graphic and information complexity, possibly differentiated for the disciplines. After this, he shall detail the levels for the individual objects per phase of the implementation process. In this regard, a table proposed in the directive, which suggests specific ranks differentiated by discipline, stage, and phase of the action, comes to our aid. This is where the problem arises. The standard levels are conceived owing to a forward engineering methodology, where the geometrical and informative contents increase as one moves from the idea to the concrete element. Based on these observations, referring to an existing building surveyed and then modelled, one might be led to attribute the product to a *LOD G*, where the digital objects express the updated virtualization of the state of an entity at a defined time, containing the trace of management, maintenance, repairs, and replacements carried out throughout the life cycle of the work [16]. While this direct correspondence may apply to the geometric aspect (we will see that the question is more complex than it seems), the same does not exert to the information content, which is dependent on the cognitive process.

A solution to the problem could be to decouple the two aspects, already identified by UNI standards as Geometric attributes (*LOG*) and Information attributes (*LOI*), which however cannot be treated separately today. A big problem concerns the geometry. Just think of the detailed knowledge of the stratigraphy that must be achieved to reach a *LOD G*. This is certainly a simple but revealing example. Returning to the case study, based on the above considerations, it is not possible to acquire deep knowledge for all information and geometric aspects. The same architectural survey, carried out with photogrammetric and laser scanning techniques, is limited to an exhaustive documentation of the 'skin' of the building, without however providing information regarding the 'non-visible' elements, such as the stratigraphy of the walls. It is therefore evident that the LOD system needs to be rethought in relation to the type of building, as it is extremely difficult and above all costly for a private individual to implement the techniques and technologies necessary to collect the missing data [17].

For this specific case, models and outputs deriving from the survey are integrated with documents of various kinds (projects, deeds, etc.) in paper format and historical images rigorously archived by the owners, in order to outline a cognitive framework compatible with the objectives and uses of the model. It is therefore possible to achieve a *LOD G* for all virtualised architectural elements, although it is not practicable to validate all geometric and non-geometric attributes in the field. This is a major problem, but one that could not be solved by solutions economically compatible with the client's availability.

Fortunately, UNI EN ISO 19650 and UNI EN 17412, with the introduction of the LOIN concept, allow us to go beyond the static approach of LODs and to calibrate the information contents with respect to a conscious and mature demand, providing in fact mixed LODs for virtualized elements.

2.5 Technical aspects of BIM and model construction

The data obtained from the historical documentation collected by the owners are certainly not sufficient to guarantee the achievement of a *LOD G*. For this reason, we opted for the preliminary construction of a reality-based model for the building and its surroundings, applying a reverse engineering methodology. The formalization of a schematic procedural pipeline in the acquisition and management of data derived from the digital survey represents a fundamental step preceding the development of the BIM model. Regardless of the hardware and software tools used, it is possible to identify a succession of methodological phases that characterize a Scan-to-BIM procedure: survey design and data acquisition, processing, object recognition and BIM modelling. The application of the described sequence guarantees an overall quality of the product such as to set up a solid base for the following operations. The workflow proposed for the case study aims to assure the traceability of the entire model building process, which is a prerequisite for ensuring that it can be updated and reused (Fig. 2. 4).

Survey project and data capture

The design of the survey plays a decisive role in the documentation process, though often underestimated in the execution of a scientific investigation, where it is necessary to maximize the quality of the results and minimize the time needed.

When we work on an object, the planning and design of an intervention like a survey or the production of a reality-based or source-based virtualization must necessarily start by analysing the requirement framework. The models and outputs we generate must meet a precise purpose, and one or more uses must be planned for them. All these factors are therefore fundamental in defining their

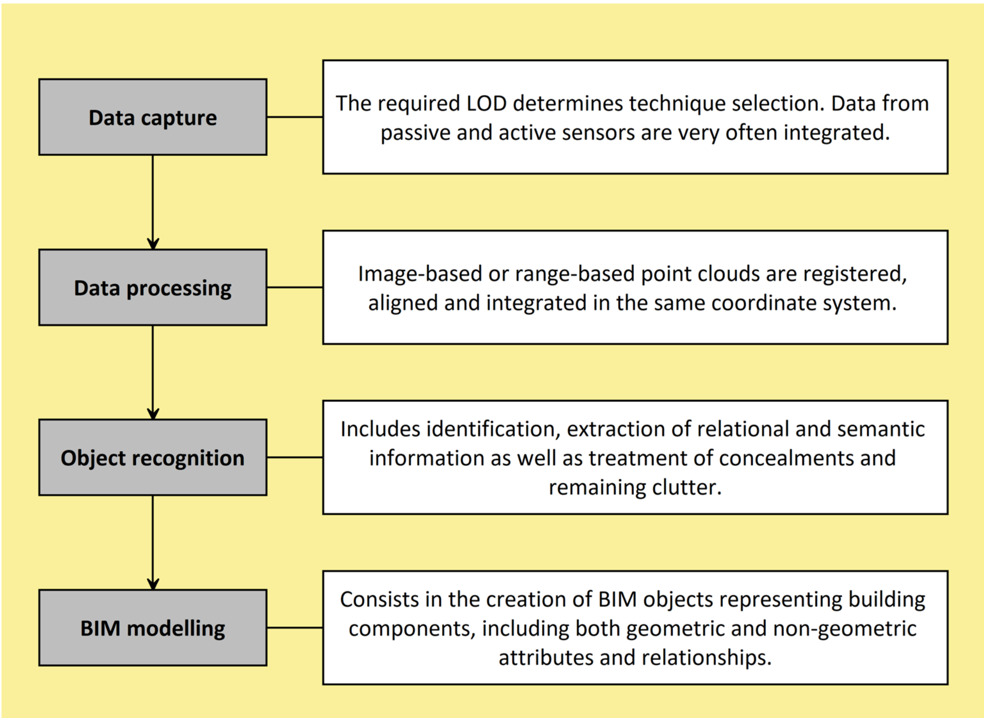

Fig. 2. 4. Scan-to-BIM (reverse engineering) workflow (author's elaboration).

features, such as the Level of Development of the objects, geometric accuracy, and other apparently trivial aspects such as the file storage format.

There are more factors to be taken into consideration, which are not linked to the requirements but to the attributes of the case study, such as its state of conservation, the properties of the materials, and the boundary conditions. All these elements can sway the choice of tools and techniques to be used. The distinctive features of a model/output are then related to factors that we could define as external, such as the available budget and the delivery time. The analysis of the reference context, characterized by a closed settlement typology typical of intensive areas, with a dominance of built-up blocks and building and urban indicators reaching critical values, led us to opt for a combination and integration of different detection techniques and technologies, maximizing performance. The terrestrial laser scanning (TLS) guarantees high accuracy and, although it is characterized by long acquisition times, this factor does not become incisive given the small size of the block under investigation. UAV photogrammetry makes it possible to comprehensively document roofs, which are difficult to access and link to other elements of the scene. Close-range photogrammetry guarantees a photorealistic reconstruction of the elevations, which is useful for the analysis of chemical and physical phenomena affecting the building.

Topography

The frame outlined seems complex and there are many variables to consider. However, the first step to be taken in the design of a survey brings together all the possible scenarios: the execution of an inspection aimed at defining a topographic reference network to form the backbone of the subsequent acquisition phases. Its functions are multiple. Foremost, it identifies the stations from which to detect the detail points necessary to provide a correct description of the object and the integration of data deriving from different techniques. Secondly, the framing and detail points also make it possible to check the accuracy of the multiple solutions used for documentation. Finally, the topographic survey allows the identification of a common reference system for all the source-based models, according to the technical section of the *CI* and compatibly with the client's indications. In the case study, the network consists of a closed polygon with 4 framing points, the latter being subject to geometric levelling operations for a rigorous plano-altimetric detection (Fig. 2. 5). For measurements of azimuthal angles, performed with a total station, we make use of Bessel's rule.

The topographic survey is supplemented and combined with GNSS positioning techniques, using a single receiver on the vertices of the network in order to perform its compensation and insert it into a national reference system. For an integrated use of the different sources, it is necessary to take care of the geolocation, expressed in a Geodetic Reference System recognized by the regulations in force; in the case of Europe this system is the ETRS89, which in Italy translates into the

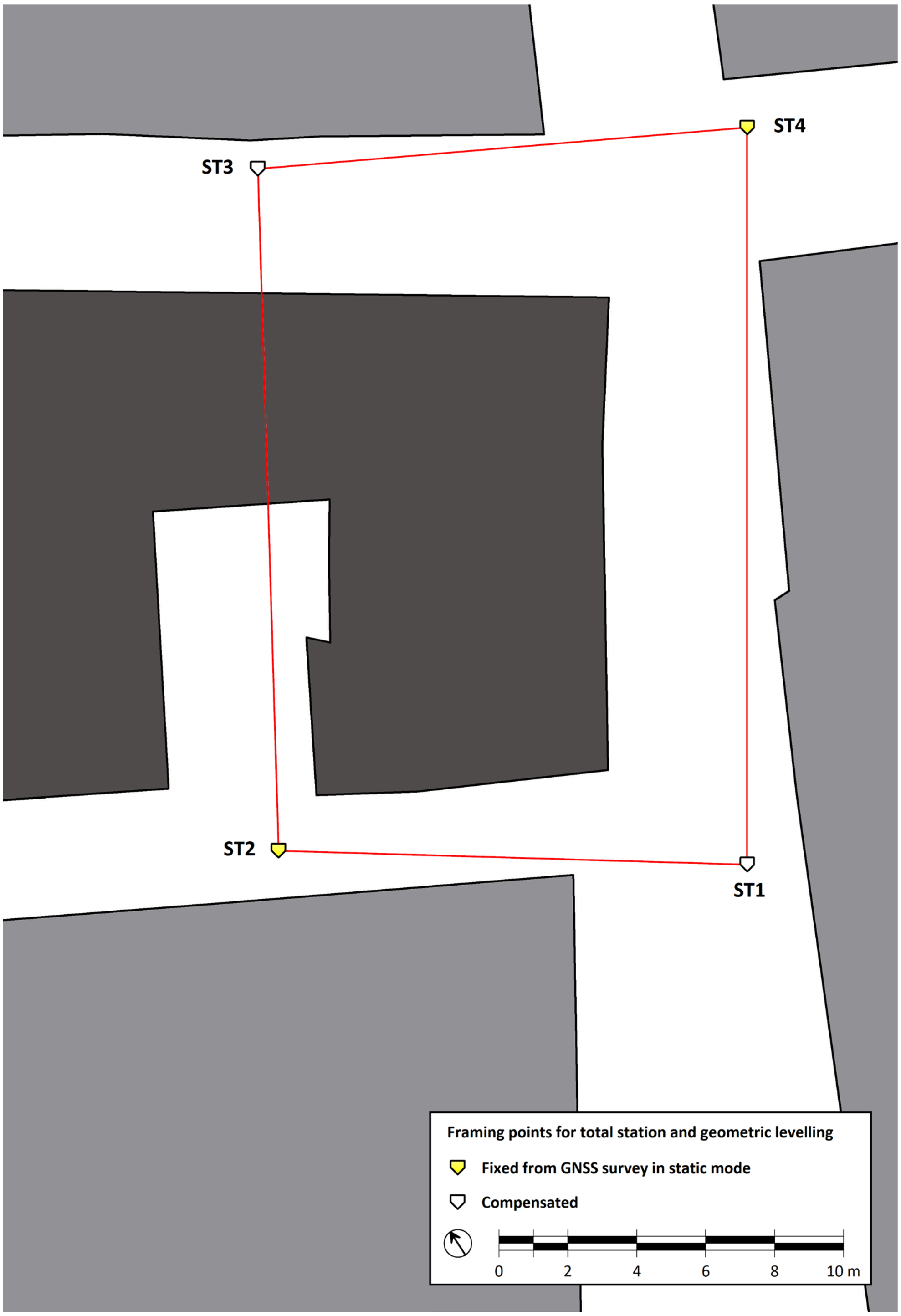

Fig. 2. 5. Structure of the reference network used for the integration of the survey data.

realisation ETRF2000 (epoch 2008.0). The use of the latter, based on the GRS80 ellipsoid, is an obligation for the Public Administration, sanctioned by *Decreto del Presidente del Consiglio dei Ministri del 10 novembre 2011* (administrative document), as well as indicated in the European directive INSPIRE (Technical Guidelines Annex I - D2.8.I.1). For the municipality of *Siano*, therefore, the cartographic reference system required by law will be UTM33/ ETRF2000 identified by code EPSG:7792.

GNSS acquisitions are performed in static mode (sampling rate 1") for two vertices of the network, whose coordinates will be considered known. For the reminder, approximate coordinates are acquired using nRTK measurements. In both cases, an elevation angle of 15° is used. The data are processed in single-base mode and, for the static application, precise ephemerides are downloaded 28 days after the date of the survey for the satellite trajectories.

The framing points of the reference network are materialized through centring nails, fitted with washers and driven into the road pavement (Fig. 2. 6) while, for the detail ones, artificial checkerboard targets are used, appropriately distributed on the faces of the block for a total of 17. Monographs are drawn up for the reference points, accompanied by sketches and photographs.

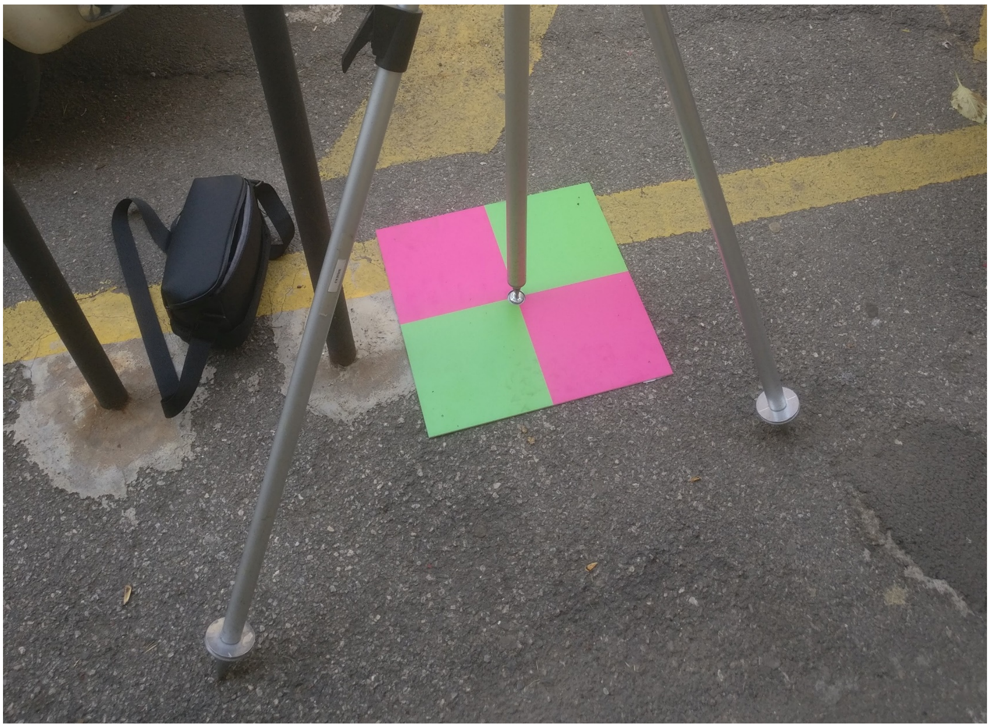

Fig. 2. 6. Positioning of the post on the ST1 station centring nail with UAV target.

Terrestrial laser scanning

In defining the TLS stations, we consider several factors: firstly, the correct acquisition of the checkerboard targets, which are essential for the geolocation of the overall cloud. This is not sufficient to guarantee a quality survey [18]. We then consider the expected density of the final model, in relation to the geometries of the investigated scene. By imposing a spacing between points of no more than 5 mm for the output, we set the scanner resolution to 6 mm at 10 m for exteriors, where the distance between device and building is never more than 7 m (for the upper levels, scans are made from the loggias and balconies of the surrounding constructions), and 12 mm at 10 m for interiors, where the average distance is reduced to 3 m.

We then consider the overlap between scans, which is essential for robust registration of individual clouds based on Bundle Block Adjustment. This parameter, imposed at 30% between consecutive stations, allow us to define the distance among them and to ensure appropriate laser incidence angles. These distances are, of course, very variable between inside and outside and related to the complexity of the spaces.

To further optimize subsequent registration operations, we distribute 120 encoded targets in the scene. These can be automatically identified by most processing software, which associates a unique number to them. The advantage is remarkable because target-based pre-registration will be less computationally burdensome as it is based on a name match rather than a geometric one. In addition to the encoded targets, the 17 checkerboards, which are essential for the geolocation of the overall cloud, are also detected (Fig. 2. 7, Fig. 2. 8).

Four measurements are taken for each surveyed point and then averaged. The project contains 85 scans: 25 externals, for which photos are acquired to achieve RGB colouring, and 60 internals, for which is performed a representation based on the intensity of the laser beam reflected from the investigated surfaces, depending on distance, angle of incidence, material properties, colour, and boundary conditions.

The instrument used for the survey is the FARO Focus^{3D} X 330, a stationary laser scanner of the Continuous Wave- Frequency Modulation (CW-FM) type (Indirect Time of Flight or Phase Shift).

Close-range photogrammetry

This monoscopic multi-image photogrammetry application uses a Fujifilm X-T100 mirrorless camera (24.2 MP, 23.5x15.7 mm APS-C CMOS sensor with primary colour filter) equipped with an XC 15-45mm F3.5-5.6 OIS PZ lens, mounted on a tripod in landscape orientation and operated by remote control. The frames captured have a pixel size of 6000 x 4000.

The goal is to digitally reconstruct the three free elevations of the building block. The most critical aspect of this acquisition campaign lies in the fact that, at street level, the distance from the surrounding constructions is small (about 5 meters), imposing a considerable inclination of the camera axes on the horizon to document the upper floors.

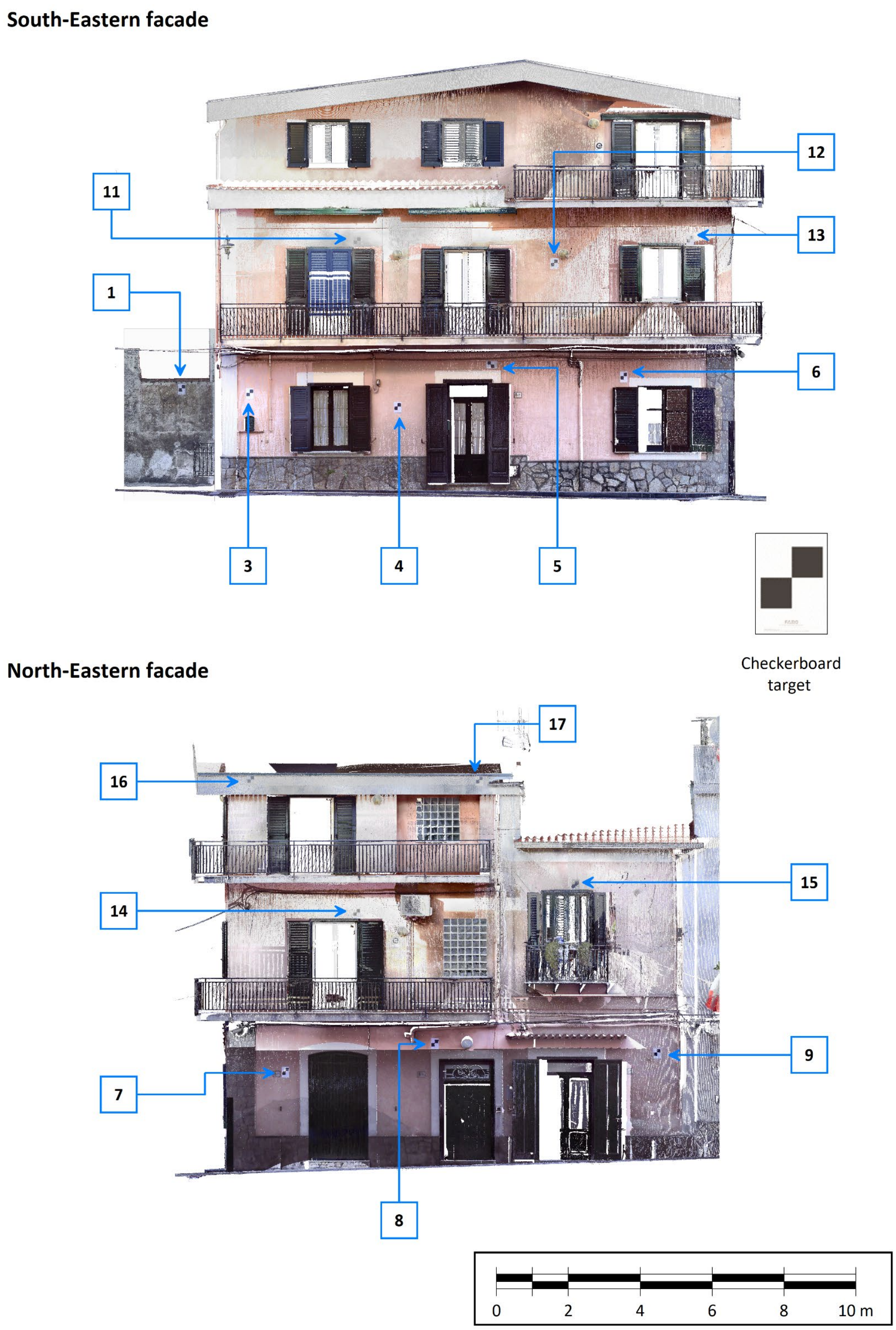

Fig. 2. 7. Checkerboard target distribution on the South-Eastern and North-Eastern facades.

Fig. 2. 8. Distribution of the checkerboard targets on the South-Western facade.

This would result in an inaccurate reconstruction of these regions. To solve the problem, we operate as follows. Considering the distance from the building to be 4.5 m (a small approximation is made as we should know the gap between the projection centre and the object) and setting the focal length at 20 mm (which comes near to the main distance), we obtain a GSD of about 0.88 mm for the ground floor area. A first swipe is made starting from a position in which the axis of the camera is perfectly orthogonal to the façade (vertical) and rotating the instrument upwards around a horizontal axis parallel to the front. This movement is carried out always ensuring a longitudinal overlap of 60%. Once the swipe is complete, we move parallel to the building, guaranteeing a 50% side overlap and continuing with a new downward swipe.

We then proceed with this pattern, gradually curving into the cantonal areas, where consecutive elevations are connected. In order to ensure the correct reconstruction of the architectural elements placed at different depths with respect to the plane of the façade, such as cornices, horns or door and window openings, the scheme is repeated several times starting from positions where the axis of the camera, while remaining horizontal, is not orthogonal to the front but is oblique.

To avoid reconstructing some areas with frames for which the axis forms excessively acute angles with the façade, we replicate the procedure by positioning ourselves on the balconies and loggias of the surrounding buildings, thus also ensuring better control of the GSD.

As for the other camera parameters, these are defined in relation to the hyperfocal focusing technique. Firstly, the ISO sensitivity values are kept low (200) to avoid the formation of digital noise. Obviously, this decrease the shutter speed to obtain a correct exposure, but it is not a problem in this case as the camera is used with a tripod.

The hyperfocal technique allows the depth of field to be maximized and extended to infinity. This quantity depends on the focal length, which is already fixed to obtain a specific GSD, on the focus distance, on the circle of confusion, calculated using the Zeiss formula (≈ 0.019 mm), and the aperture of the diaphragm. If the latter is lower, it produces a smaller hyperfocal distance and an area of sharpness that is closer to the camera. Conversely, there is a progressive loss of sharpness and any impurities on the sensor are highlighted. A compromise must be found.

Since the minimum gap between the camera and the objects in the scene is around 3 m (protruding elements such as balconies are considered), the aperture is set to f/5.6, so that the hyperfocal distance is approximately 3.77 m and the sharp area starts at about 1.88 m from the camera and extends to infinity.

The shutter speed is evaluated each time to obtain the correct exposure. The technique used therefore requires manual focusing, which is another positive factor since the main distance, which is related to both the focal and the focus distances, will not change during the acquisition campaign as the focus will only be adjusted once, before starting to capture the photos. In total, the dataset consists of about 600 images, ready to be oriented with a shape-from-stereo approach.

UAV photogrammetry

For this acquisition campaign, we use a DJI Mavic Mini 2 UAV, with a Maximum Take Off Mass (MTOM) of 249 g and equipped with a 12 MP (4000 x 3000) camera. The sensor is a 1/2.3’’ CMOS and the lens has a field of view (FOV) equal to 83°, a focal length of 4.49 mm and an f/2.8 aperture. The ISO sensitivity is set to a value of 100 to avoid noise formation and the captured frames have a pixel size of 4000 x 3000.

The technical specifications currently place it in the Limited Open Category A1 defined by the European Union Aviation Safety Agency (EASA), allowing it to fly over people not involved in operations, present in an urban context such as that of the case study.

Starting from these elements, a flight altitude (H) of 17 m is planned (with respect to the ground homing point) in order to obtain a GSD at street level of about 6 mm/pixel (in the calculation are performed the same approximations seen for the close-range photogrammetry). As far as the flight plan is concerned, we start with nadiral shots from double orthogonal grid pattern. Knowing the flight altitude, we calculate the size of the effective area contained in the frame (23.85 x 17.80 m) and, assuming a crawl advancing in the direction of its smaller side with 70% overlap, we determine the baseline (B), equal to about 5.34 m. This value ensures a B/H ratio above the minimum optimal threshold of 1/4, derived from experience. We then calculate the distance between the strips in the direction of the width, setting a side overlap of 60% and obtaining a value of approximately 9.54 m (Fig. 2. 9). Enclosing the area to be surveyed in a square of about 23 m side, we estimate the number of frames in a swipe (5), the quantity of swipes (3) and the total count of frames in a single grid (15), to be doubled (Fig. 2. 10). The effects of drift are neglected and, as far as drag is concerned, we plan to stop the drone and make it stabilize on each capture position before acquiring the frame (an important contribution to the stabilization of the camera is related to the work of the gimbal). The shutter speed is adjusted each time to ensure correct exposure.

The nadiral frames are integrated with the oblique ones, which are divided into two sets, acquired in a double grid pattern. By tilting the camera 30° with respect to the vertical, we recalculate the elevation, the effective dimensions of the detected area, the baseline, the distance between the strips and the number of frames of the survey. For each set we obtain 40 images. The acquisition is completed with a circular trajectory flight, centred on the built-up block and with a radius of 20 m. The axis of the camera is tilted 30° from the vertical and the flight altitude is 20 m, capturing 125 frames. For drift, drag and shutter speed, the same considerations apply as for nadiral images.

Before starting the campaign, we check that the flight plans are compatible with the air traffic restrictions for low-altitude reported, for the area of interest, on the d-flight platform managed by *Ente Nazionale per l'Assistenza al Volo* (*ENAV*, an Italian joint-stock company operating as an exclusive provider of civil air navigation services in the airspace under national jurisdiction).

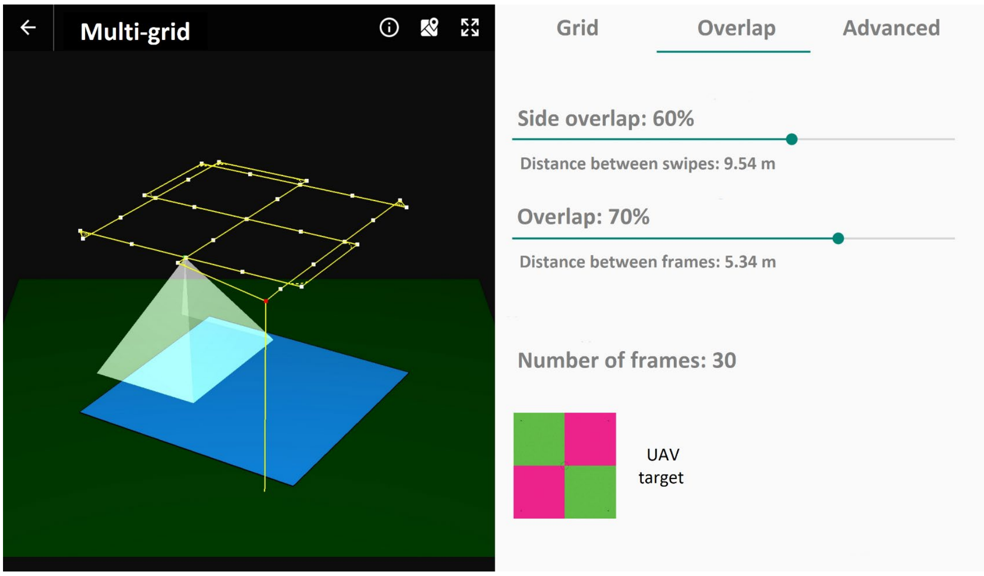

Fig. 2. 9. Evaluation of overlaps for the nadiral frame acquisition and UAV target selection.

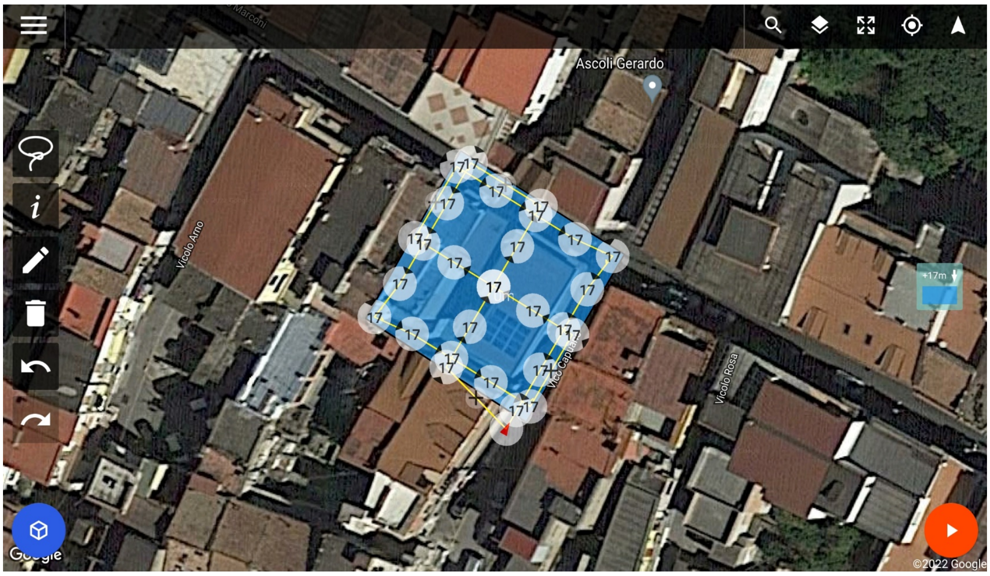

Fig. 2. 10. Flight plan map with double grid and flight height for nadiral frames.

Data processing

As already mentioned in the section on survey design, the individual instruments and methods are marked by peculiarities that make them unique both in the way data are acquired and archived (type and format). This strong characterization represents on the one hand the distinctive factor, if the application is compatible with the performance of the instrument. At the same time, however, it severely limits its exclusive use if the survey conditions are complex, as seen in the case study.

The uniqueness of the specific application may require a performance range that individual solutions can hardly offer on their own. In this circumstance, integration between systems allows the best possible result to be achieved in terms of accuracy as well as optimization of the entire reality-based modelling process.

Today, twenty years after the first experiments in the field of documentation, the theme of integration in 3D survey is a central topic of research in various disciplines, within which new methods are being studied to solve the problems of compatibility between different technologies in an automatic or semi-automatic way, enhancing their potential [19].

The approach to integrate multiple acquisition systems involves three components: information representation, uncertainty description, and method optimization. From an operational point of view, this translates into the fact that there are some main purposes in the integrated application of two or more sources: to increase the information about the object and to verify, or often improve, the level of global accuracy. In the first case, the model is solved through a primary spatial acquisition, enriched with progressive additions that allow a better readability. The second and more complex aspect concerns the overall accuracy of the model, a very delicate issue for those who deal with three-dimensional survey for the purposes of documentation, restoration, and conservation. Its centrality depends precisely on the great and obvious difference between the quality and accuracy of the single data detected compared to the overall accuracy of a model: while the first is substantially related to the type of instrument and the ability of the technician, the second is obtained only at the end of a complex process in which many critical factors intervene. In this sense, the integration between different systems can operate on two levels: on the one hand to verify the level of accuracy of the overall model produced by the fusion of multiple range maps through the application of instruments that ensure a degree of accuracy known on the global measurement; on the other hand, to improve the accuracy of the entire virtualization avoiding incurring in local errors that can be propagated over the model surface.

Based on these aims, it can be stated that the 3D integration from different sources is pursued by acquiring as much information as compatible with each methodology used, thus introducing a certain amount of redundancy, but at the same time minimizing the impact of measurement uncertainty both in the survey phase and in the creation of the digital model, and collecting a quantity of geometric data suitable for the generation of variable resolution products.

Since these first general considerations, it appears evident that active and passive techniques are not in competition but complement each other, given the different performances of accuracy and control of geometric acquisition, particularly useful when you must deal with very pronounced dimensional dynamics.

Although there are several surveying techniques and sensors that allow to generate realistic 3D models, defined by a good metric quality and a detail coherent with the geometric characteristics of the virtualization, the best approach for surveying consists in the combination of different tools and modelling techniques. In fact, the use of a single 3D technology does not allow, now, to reach a satisfactory result in all working conditions and in terms of geometric accuracy, portability, automatism, photorealism, and low costs, with the same efficiency and flexibility [20]. For this reason, image and range-based solutions are integrated in order to exploit the full potential of each measurement technique.

This can be done with two approaches: operating at the sensor tier or at the data tier [21]. Mobile Mapping (MM) systems are the best example of first solution, allowing to obtain geolocated spatial information thanks to the combination of digital imaging devices, long-range laser scanners and GNSS or Inertial Measurement Unit (IMU) sensors [22].

On a diametrically opposite position, we have data integration, in which the sources operate independently in the acquisition phase. This approach is used for the case study and can be classified with respect to multiple parameters. The best-known framework, to which we refer for our application, is purpose-based and consists of 3 levels [19]:

- low-level, generating new data from raw sources;
- mid-level, relating the existing data;
- high-level, obtaining a complete 3D model.

Other classification systems are connected to the nature of the data (points, features, surfaces) and the geometric dimension (3D-to-3D, 2D-to-3D).

High-level applications (generally surface-based and 3D-to3D) are the most common and in them the raw data are processed independently, then combined to obtain a complete reality-based model. This is the approach mainly used for the case study, where the TLS and photogrammetric workflows remain separate until dense point clouds are produced, rigorously combined in a controlled way thanks to the data coming from the topographic survey, the element that joins the heterogeneous digital datasets.

In contrast, mid-level (generally feature-based) procedures aim to calculate relative orientation parameters between different sensors.

Low-level processes, also known as data fusion, analyse the capabilities of individual raw data to highlight critical issues and overcome them by employing complementary sources. An example is provided for the case study, where partially processed TLS clouds feed into the photogrammetric workflow to optimize the dense stereo matching phase (depth maps calculation) for the generation of the final model.

Topography

As already mentioned, the topographic campaign allows building a network, which is necessary to perform a rigorous high-level integration and to define a common reference system for the whole project.

Observations from the total station survey, geometric levelling, and GNSS are treated using the method of indirect measures. The goal is to determine the compensated coordinates of the framing and detail points (17 checkerboard targets). Vertices ST2 and ST4, surveyed with GNSS system in static mode, are considered to have known coordinates.

The method can be summarized in a simplified way as follows. The m observations are related to the n unknowns (not necessarily all of them) in relation to the measurement approach. Each observation generates an equation where the possible unknowns appear, which can be linear or non-linear. Since m > n, there will be no solution that simultaneously satisfies all the equations. As a matter of fact, having a hypothetical vector of solutions to replace in the system, a vector of residuals is generated. These are produced by the fact that the observations are subject to errors. The functional model therefore has m equations (the observations) and m + n unknowns (vector of unknowns and residuals) with ∞^n possible solutions [23].

A criterion must be adopted to select one solution from the infinite possible ones. The chosen one is that of the least squares applied to the residuals, which makes it viable to find the solution for the vector of unknowns (n) such that the sum of the quadratic residuals is minimal (stochastic model). It is then possible to obtain indications of the precision of the results by considering standard deviations on compensated vertex coordinates (Table 2. 2) and calculating the covariance matrix associated with the estimated parameters, from which the standard error ellipsoids for the point coordinates can be obtained [24].

Terrestrial laser scanning
TLS scans are the result of millions of measurements that have been taken and, just like any other observation, various grades of accuracy are achieved. Depend-

Table 2. 2. Standard deviations on compensated vertex coordinates.

Point ID	σ Easting (m)	σ Northing (m)	σ Height (m)
ST1	0.0011	0.0003	0.0013
ST2	Fixed vertex		
ST3	0.0000	0.0006	0.0001
ST4	Fixed vertex		
1	0.0012	0.0013	0.0005
2	0.0014	0.0007	0.0002
3	0.0012	0.0015	0.0003
4	0.0009	0.0005	0.0011
5	0.0014	0.0013	0.0008
6	0.0004	0.0011	0.0013
7	0.0012	0.0003	0.0005
8	0.0005	0.0007	0.0010
9	0.0006	0.0013	0.0012
10	0.0009	0.0002	0.0004
11	0.0007	0.0013	0.0010
12	0.0010	0.0011	0.0015
13	0.0006	0.0014	0.0010
14	0.0014	0.0007	0.0008
15	0.0010	0.0005	0.0014
16	0.0012	0.0014	0.0010
17	0.0005	0.0011	0.0007

ing on the detection technique, there are many causes that influence the acquisition. Sources of error can be divided into four groups: those related to the instrument (laser beam propagation and tangency, distance and angular uncertainties, calibration), those dependent on the object, those influenced by the operating conditions (temperature, atmosphere, interference from radiation, micro-movements) and methodological sources [25].

If we exclude the latter, all others can be checked by additional measurements but, for reasons of time and survey efficiency, this is almost never possible and these points must be removed or corrected by subsequent processing.

The first operation performed on the raw scans is, therefore, to apply filters which, by examining all the points of the individual cloud, identify inaccuracies and correct them. Obviously, it is necessary not to overdo the application of these strainers in order not to compromise the quality of the original data.

For the case study, we operate in Faro SCENE environment (version 2019.0. 0.1457) and we apply a set of three filters: stray items, dark scan points and edge artefacts. The first removes points resulting from hitting two objects with the laser spot or by detecting no element at all, for example the sky. These problems are related to the tangent beam phenomenon and specific environmental conditions. The filter operates on structured clouds and is governed by 3 parameters: grid size, distance limit, allocation threshold. The first (expressed in pixels) is the size of the surrounding area used for comparison. For each point, the filter takes the valid scan points of this neighbouring area and numbers how many of them are at a distance to the instrument which is approximately the same as the gap of the point currently being viewed. A point is counted if the difference in distance is smaller than the gap threshold (m). If at least the percentage of scan points indicated by the allocation limit (%) in the surrounding area is also within this distance threshold, the point remains in the cloud. Otherwise, it is removed. However, the strainer must not be applied on surfaces that are strongly inclined versus the laser beam. For our application we use a 5x5 grid, a distance threshold of 2 cm and an allocation limit of 50%.

The filter for dark scan elements has a very simple criterion: the selection process is based on the reflection value of the dark points. The Reflectance Threshold value indicates the minimum reflection value a point must have. This principle is useful because with a dark point only a very small amount of light entered the scanner and therefore the measurement will have an increase in noise. The threshold varies between 0 and 2048 (11-bit depth) and we have used a value of 100. The edge artefact strainer, finally, is especially useful to remove incorrect elements at the borders of objects.

After filtering the raw data, we proceed to associate an RGB information with the individual points and register the scans. The latter phase starts with a target-based pre-recording. For this purpose, 120 encoded targets are distributed in the scene and automatically detected for an accurate identification of their centre (Fig. 2. 11). The coding allows relating to these points a numerical key that uniquely defines them

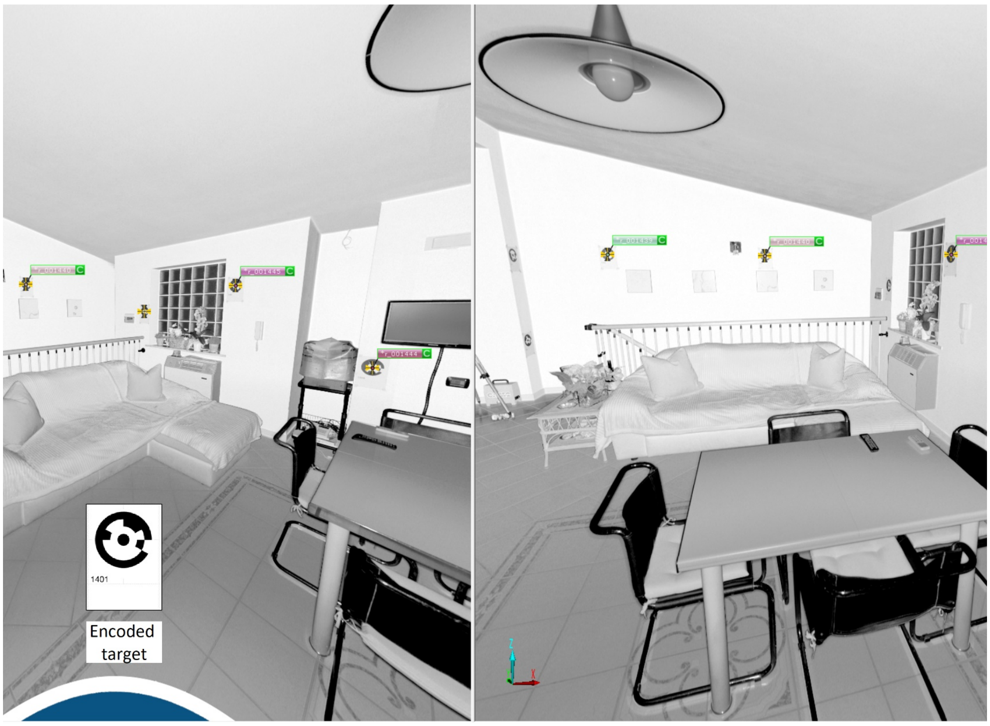

Fig. 2. 11. Search for matching encoded targets at two adjacent stations.

and simplifies the whole process. The association of homologous points will not be based on geometric features, the extraction of which is computationally burdensome, but will make use of a simple correspondence between keys.

This is followed by a fine registration using the Bundle Block Adjustment. Given the set of clouds, the algorithm creates as many connections among pairs of neighbouring scans as possible, employing the pre-registration report. For each correlation, a pairwise Iterative Closest Point (ICP) is executed, selecting amid three levels of severity for the acceptance of matches. In this case, we opt for the highest one. From each ICP, the best corresponding point pairs between the two scans are saved. In the end, a final nonlinear minimization step is run only among these matching point pairs of all the connections, reducing their global registration error and having as unknown variables the scan poses. All posing operations are carried out considering the data from the instrument's inclinometer, avoiding the use of the compass, which is too sensitive to electromagnetic interference.

This is followed by the geolocation phase of the overall cloud. The coordinates of the 17 checkerboard targets, estimated by topographic survey, are imported as external reference objects into the processing software and loaded in a specific cluster, placed at the same level as the one containing the scans. In this way, we can perform a target-based registration using the external objects as higher-quality reference and automatically extrapolating the centres of the checkerboard from the individual scans, without invalidating the fine localization. A quick verification of the goodness of the process can be performed by checking the discrepancies between the coordinates of the external references and those of the checkerboard targets automatically extrapolated from the scans. In our case, they have an average value of 2.4 mm and a maximum of 4.8 mm.

Finally, we manually clean the clouds, removing areas of no interest, excessively distant or acquired at acute angles of incidence, and generate an overall model. This allows us to delete duplicate elements that always exist when they are recorded from different scanner positions. Overlapping areas can be optimized by removing some of them and improving the visual quality of the cloud significantly while reducing overall point count and therefore upgrade interactivity and loading times. It is also possible to balance the density of the cloud in excessively heavy areas by setting the size of the homogenization cell, fixed at 3 mm in our application. This provides an easily manageable reality-based model without sacrificing the resolution needed to carry out the possible subsequent operations, such as deformation analysis, the study of crack patterns and source-based description.

Photogrammetry

As far as the photogrammetric process is concerned, the workflow applied for data from mirrorless camera and those obtained using UAV are described together given the similarities and the use of the same software environment, making the necessary clarifications for the individual case. For the avoidance of doubt, it should be noted that the data are processed in two separate projects.

The first step is to import the images. Agisoft Metashape Professional (version 1.8.2 build 13956), the software used for treatment, does not support proprietary raw formats, so a conversion must be made. In both projects, we use a lossy JPG sRGB 24-bit type, a good compromise between file size and quality. Blurred images may affect the output. We therefore estimate their sharpness. The method used consists of a comparison of the contrast gradients in the most peculiar areas of the source photos, considering the originals and pictures with the Gaussian blur filter applied. The resulting indicator can take values greater than one and we exclude from the process all frames with a rate less than 0.5.

We then check the calibration table. Since, for each project, the uploaded images have no differences in size, focal length or other parameters extracted from the exchangeable image file (EXIF) format information, the software creates a single calibration group (CCG). Therefore, we check the camera type (frame), pixel size, focal length and, for UAV photogrammetry, the GPS/INS offset characteristic of the vehicle before proceeding further. In both cases, no pre-calibration data are available for the cameras and no key point and tie point masks are used.

Before image orientation, we need to check the reference settings. In the UAV photogrammetry, location information is contained in the EXIF and can be employed to speed up the search for tie points. In detail, camera positions are ellipsoid coordinates with respect to the WGS84 reference system (EPSG:4326). The procedure could be further optimized by entering the values of other parameters such as capture distance (average ground height in the same coordinate system which is set for camera data, particularly useful if nadiral and oblique images are combined in the project) and orientation angles (yaw, pitch, roll or omega, phi, kappa) for individual photos. In our case, we do not have this information, but it is not a problem as it becomes relevant for alignment quality if the oblique frames are tilted more than 30° on the vertical, which is not the case in the project. Source reference preselection will consider only longitude, latitude, and altitude coordinates for preliminary identification of the overlapping image pairs.

However, these position data are not accurate, as they are not corrected by specific techniques such as nRTK, but they can still be used in the early stages of the process [26]. For this reason, we select the reference system mentioned above for the cameras only. For close-range photogrammetry, we have no position data and therefore we set a local system for the cameras.

We can then proceed with the orientation. Metashape detects points in the source photos which are stable under viewpoint and lighting variations and generates a descriptor for each point based on its local neighbourhood. These entities are used later to identify correspondences across the photos. This is like the well-known scale-invariant feature transform (SIFT) approach, but uses different algorithms for a higher alignment quality (feature detection). The software then applies a greedy procedure to find approximate camera locations (feature matching) and refines them later using a Self-Calibration Bundle Block Adjustment (structure estimation, Fig. 2. 12) [27]. The latter solves the problem of internal and relative external orientation at the same time. A list of parameters governing the process follows:

- accuracy defines how the original data are down-sampled in relation to their pixel size. The high setting, employed for the two projects, lets us work with images in their full dimension;
- the generic preselection option, used in the applications, allows photos to be matched using a sub-sample first, and then to be optimized in original resolution. This accelerates the process but can return fewer overall tie points;
- for reference preselection, we activate the source option in the UAV photogrammetry. This uses the coordinates of the images to speed up alignment. In our case, we do not consider additional data such as orientation angles

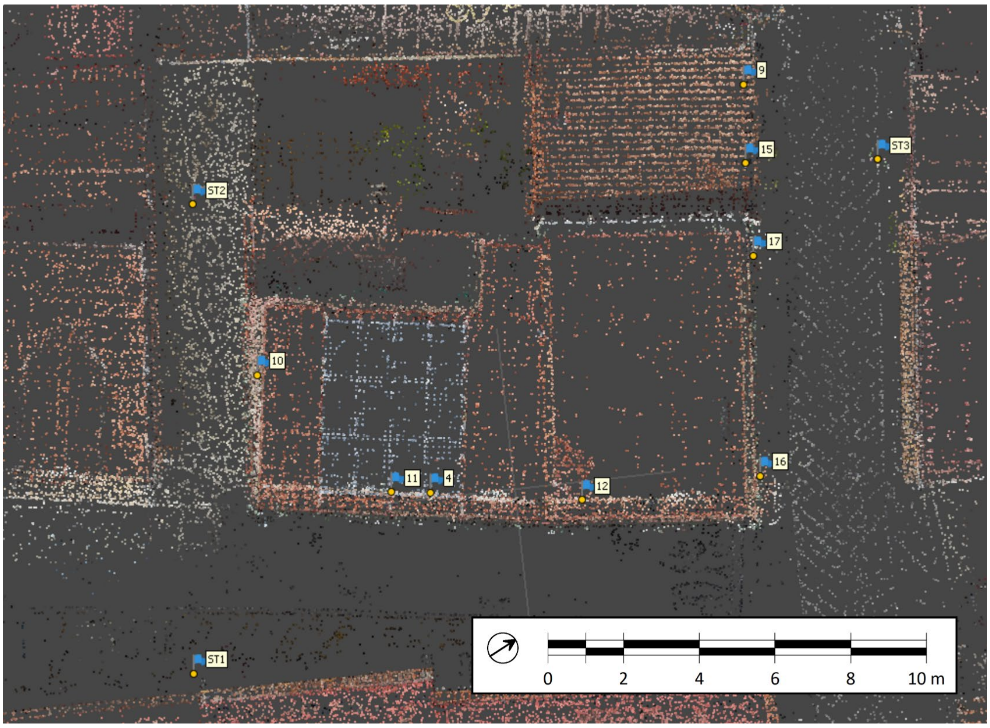

Fig. 2. 12. Top view of the UAV sparse cloud obtained from the structure estimation phase.

and capture distance but, as anticipated, the difference is not substantial since the oblique frames have an inclination on the vertical that does not exceed 30°. For close-range photogrammetry we use the sequential option instead, based on the order of the camera labels;

- the key point limit is set at 60,000. Higher values would return more points, but their reliability would progressively decrease. The Metashape user manual suggests a limit of 40,000, but with the high-quality images used in the workflow, an upper limit still guarantees solid points;
- tie points are not restricted as they will be thinned after alignment. In the case of a medium-sized dataset like ours, this does not cause any problems;
- the adaptive camera model fitting option is deselected. In this way Metashape will refine only a fixed set of parameters related to the internal orientation, including focal length, principal point position, three radial distortion coefficients (K_1, K_2, K_3) and two tangential distortion coefficients (P_1, P_2). If checked, the camera model solutions are unpredictable because the software attempts to find the 'best' combination of coefficients that reduce the model error. Letting Metashape choose for you may result in lower error, but is also an easy way to overfit the data or create a complex camera model that does not accurately reflect the equipment used, leading to underestimated or increased actual error.

The next step is to import outward references to optimize the installation and to solve the problem of absolute external orientation. In both projects, we use the coordinates of the centres of the 17 checkerboard targets, obtained from a topographic survey. These points are also visible in the photos of the two datasets and Metashape can locate them automatically, simply by choosing the type of artificial object placed in the scene (in this case uncoded cross-shaped targets). After recognition, we proceed with a visual check and eventual optimization, taking care to rename them according to the nomenclature used for the topographical survey.

At this stage, we select the appropriate reference system for the coordinates of these points, which the software calls markers. As mentioned above, the topographic data are expressed with respect to the map system UTM33/ETRF2000 identified by code EPSG:7792 (Fig. 2. 13). For small survey areas, projected coordinates (for example, UTM) are sufficient, but do not account for the curvature of the Earth, which amounts to vertical deviations from the projected plane up to about 8 cm per kilometre.

We therefore make the selection of the EPSG:7792 reference system for the markers and import their coordinates via a text file. This one also contains the accuracy values associated with the individual coordinates, which are indispensable for giving different weight to individual points in the optimization process (we are referring to measurement accuracy, which is linked to external reference data and thus to the object space, and not to the accuracy with which these points are marked in the image space, expressed in pixels, and dealt with during optimization).

About UAV photogrammetry, we can now deactivate the camera position data, which are less accurate than the data just imported and will therefore be excluded from the improvement operation.

Not all markers are used as Ground Control Points (GCPs) to solve the absolute external orientation, but some will be discarded from this process and employed as Check Points (CPs) to validate the optimization results, taking care to ensure a homogeneous distribution of the two groups in the detected scene.

We can then optimize the alignment (structure optimization). The goal is to obtain only high-quality tie points and repeatedly improve the camera model. This is the most subjective section of the workflow, and testing how many points can be removed at each stage may be necessary to create a successful product. Poor geometric relations between cameras result in points that are selected using the reconstruction uncertainty metric. Tie points to which Metashape has internally given low match accuracies are identified employing the projection accuracy criterion. Lastly, tie points that are the result of false correspondences are highlighted using the reprojection error metric. The selection and elimination processes are iterative. The removal of poor tie points will improve the estimated internal and external orientation parameters, but each time they are deleted, the accuracies of the remaining ones change, and the project requires optimization before continuing, checking the calibration section. To be fair, in addition to the three parame-

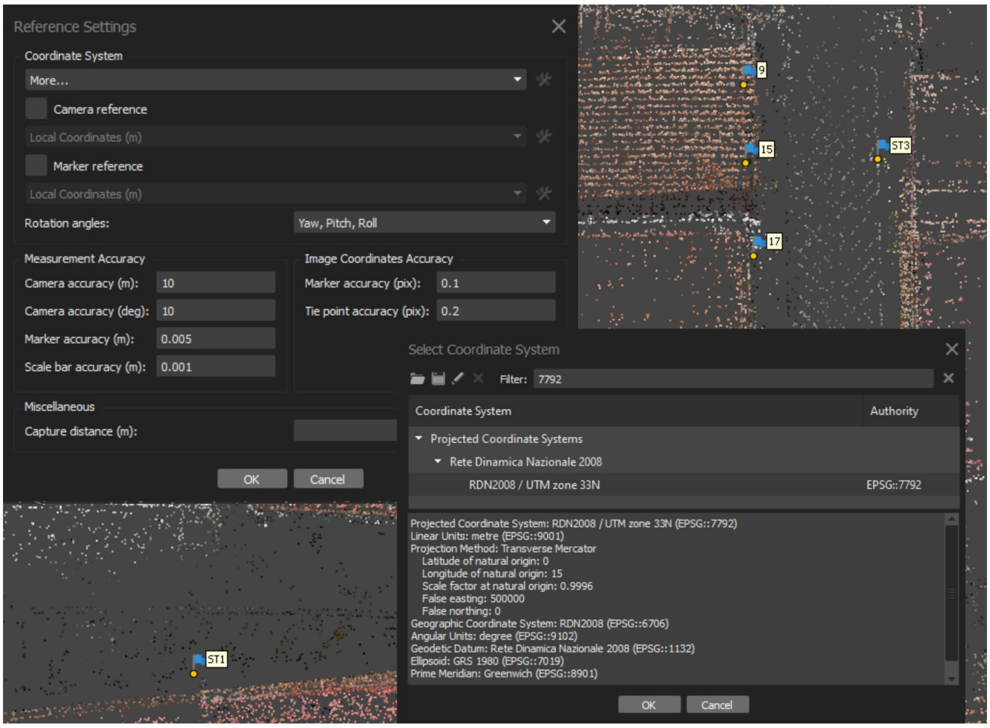

Fig. 2. 13. Choice of reference system consistent with input data.

ters mentioned above, another one must be considered: the image count. In general, the orientation can reconstruct points that are visible in at least 2 photos, but in this case, they are e likely to be located with poor accuracy. Therefore, after estimating the structure and before proceeding with optimization, we only preserve tie points that are reconstructed from at least 3 photos.

The error reduction phase relies on robust tie point and marker accuracy estimates, referred to the image coordinates quality (and, of course, on the accuracy of the measured control data in the object space). The proportion between these two parameters distributes the weight given to markers and tie points in the whole process. Correct reference settings inputs prevent misleading statistics while an incorrect estimate of them generate a not representative error models, with lens coefficients that are very sensitive to these parameters.

Tie point accuracy, measured in pixel, corresponds to the normalized accuracy of their projections detected at the scale equal to 1, considering a pyramid built applying Gaussian blur). Tie points identified on other scales will have accuracy proportional to their ranks. This helps to obtain proper Bundle Block Adjustment results, but it makes it difficult to estimate this parameter a priori. For this reason, we choose to use the default value of 1 pixel for the first optimization stages.

The accuracy of the markers (expressed in pixels and referring to the image space) depends to a large extent on how they are positioned in the frames. There is, of course, also an indirect correlation with the resolution of the photos. In the case of a strict procedure, this parameter can take on values of less than 0.5 pixels (default), but establishing this a priori is again difficult. We therefore prefer to keep it unchanged at the beginning of the optimization, and then gradually correct it during the iterations. It is worth remembering that a realistic estimate of this metric is fundamental for the success of the entire process, and an indicator of its goodness is given by the discrepancy between the error (m) and accuracy (m) values relative to the GCPs and CPs. In the case of a correct estimate, they will converge.

A method of monitoring the refinement of the camera model is to check the generated reports. They indicate the number of iterations required to calculate the lens coefficients. If it does not decrease during the process, the solution found may be divergent or the modelled coefficients may be insufficient, failing to reach an internal trigger that would otherwise end the optimization. In such cases, it is preferable to start from the post-alignment phase rather than overfitting the solutions. The reports also show the values of Sigma0, the Metashape equivalent of the photogrammetric adjustment quality indicator sigma naught (σ_0) which is the Standard Error of Unit Weight (SEUW). The farther the SEUW is from 1, the poorer the tie point accuracy is estimated to be. It is the degree of deviation from an assumed quality or how closely the RMS reprojection errors match the predefined error values. However, using it as the primary indicator for workflow monitoring is impossible because the weighting it relies on is not well documented and we will only worry about its convergence to unity in the advanced stages of optimization.

A secondary method to monitor the camera model refinement is to observe the number of projections for each image. They are the total number of valid tie points found on a given photo e, if this falls below 100, then the frame will not be used in making final products. For the case study, we use a conservative limit of 500 projections to ensure a solid orientation.

Another method covered to monitor the state of the camera model refinement is the Root Mean Square (RMS) reprojection error, which is calculated using tie point projections. Its value can be easily used to assess the quality of the optimization. The tie points are located at different map scales to improve the robustness of the process, especially if there are blurred images or photos with few distinct features or textures. Metashape uses information about the scale to weight the tie point reprojection errors; this helps the Bundle Block Adjustment, but convolutes the meaning of the mentioned metric because the scaling factors and weighting methods are not reported. Of the two posted RMS reprojection errors related to orientation, the weighted value is the first one in the units of key point scale, and the unweighted one, reported in pixels, is the second one. A lower unweighted value, in general less than 0.3 pixel, is considered ideal. Filtering out tie points in the subsequent processes may result in the unweighted RMS reprojection error increasing if the camera model moves away from a certain solution because too many tie points have been removed.

The last indicator used for our workflow is the mean key point size. Key point size is the standard deviation of the Gaussian blur at the pyramid level of scales at which the key point is found. The mean value is averaged over all their set and is related to the projection accuracy that we will analyse in the next steps.

One way to visualize the uncertainty in the camera models after each optimization cycle in the following process is to estimate the tie point covariance matrix, which is related to the execution of the Bundle Block Adjustment. The results of the evaluation can be examined by activating a specific view mode for the tie point cloud. The vector associated with each of them indicates the direction and magnitude of the largest error for the tie point estimated position (its three components are the semi-axes of the error ellipsoid determined by the covariance values). The colour code is aimed to help to perceive the general distribution of the errors across the cloud (Fig. 2. 14).

We can then proceed with the first optimization phase, which can give us the indications to guide the entire operation. It is a good idea not to activate all the coefficients at this stage. Use them all may result in lower error, but is also an easy

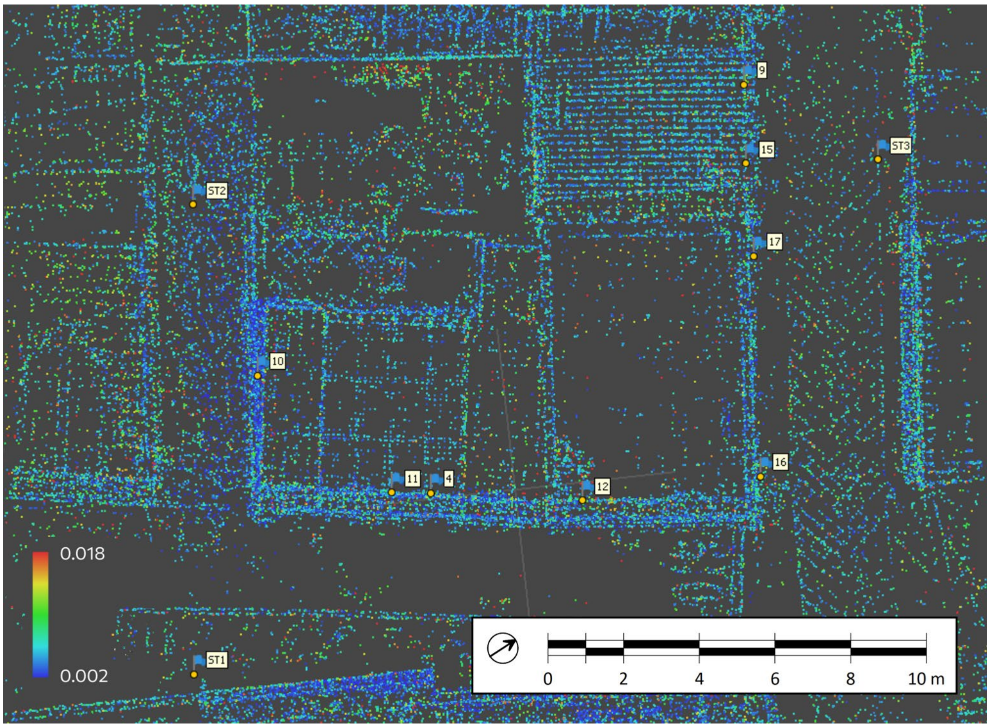

Fig. 2. 14. Top view of the UAV error vectors from covariance matrix.

way to overfit the data or create an overly complex camera model that does not accurately reflect the equipment used, leading to underestimated or increased actual error. The affinity and nonorthogonality or skew coefficients (B_1 and B_2) should be initially suppressed and only included if an inflated RMS reprojection error value indicates the possible presence of distortion related to these phenomena. The same applies to the radial distortion coefficient K_4. After duplicating the chunk containing the data processed so far to have a backup copy and checking the correctness of the input reference data, we run the first cycle selecting the appropriate coefficients, and estimating the covariance of the tie points. After this operation, we monitor the number of projections per frame and the unweighted RMS reprojection error. The latter is useful, together with RMS reprojection error on markers and mean key point size, for calibrating image coordinate accuracies.

The second phase of error reduction is to remove points that are a result of poor camera geometry. High reconstruction uncertainty is typical for points identified through nearby photos with small baseline. They can noticeably deviate from the object surface, introducing noise in the cloud. While removal of such elements should not affect the accuracy of optimization, it may be useful to delete them for better visual appearance of the reality-based model. Reconstruction uncertainty is calculated as follows:

$$\sqrt{\lambda_1/\lambda_3} \tag{1}$$

where $\lambda_1$is the largest eigenvalue of the tie-point covariance matrix and λ_3 is the smallest. Basically, it is the ratio between the largest and the smallest semi-axis of the error ellipsoid for 3D point coordinates. The latter region corresponds to the uncertainty of the point triangulation alone, without considering propagation of ambiguities from interior and exterior orientation parameters. A reconstruction uncertainty of 10 is roughly equivalent to a good base-to-height (or base-to-distance) ratio of 1:2.3 (parallax angle of about 23°), whereas 15 is almost equal to a marginally acceptable ratio of 1:5.5 (about 10°) [28]. Our workflow involves repeating the filtering of tie points on this parameter twice to reduce the reconstruction uncertainty toward 10 without having to delete more than 50 per cent of the tie points. Lens coefficients used in the optimization are the same as the previous phase. If a reconstruction uncertainty of 10 is reached in the first attempt and less than 50 per cent of the tie points are selected, a single process after deleting them is sufficient. Repeated filtrations have diminished returns and may overfit the camera model before more-poor-quality tie points are removed. Once again, we monitor the status indicators used during the first cycle.

The third error reduction phase removes points based on projection accuracy, the average image scale at which picture coordinates of the tie-point are measured, computed as:

$$\sum_i {}^{s_i}/_n \tag{2}$$

where s_i is the image scale at which corresponding projection are identified on the i^{th} image and n is the number of photos where tie point is detected. This criterion allows filtering out points whose projections are relatively poor localized due to their bigger size. It is also related to the key point size; lower standard deviation values are more precisely located in space. Projection accuracy is essentially a representation of the fidelity with which the tie point can be known given the size of the key points that intersect to create it. Metashape saves an internal accuracy and scale value for each tie point as part of the correlation process. The highest reliability points are assigned to level 1 and are weighted based on the relative size of the pixels. A tie point allocated to level 2 has twice as much inaccuracy as level 1. Not all projects can tolerate removing points at a level of 2 to 3, particularly if the images have undergone compression or are of a lower quality from noise or blur. A gradual selection level of 5 or 6 may be the best that can be obtained. The threshold limit can be defined by remembering that this filtering phase should not eliminate more than 50 per cent of the tie points inherited from the previous one, orienting on two cycles. Lens coefficients used in the process are the same of the second step. Repeated applications have diminished returns and may overfit the camera model. If the project can support an initial filtering of level 3 without selecting more than 50 percent of the tie points, a single optimization after deleting the points is sufficient. In our applications, the threshold values are 2 for close-range photogrammetry and 4 for UAV. Once again, we monitor the process quality indicators before going any further.

The second and third phases of the optimization are not directly related to the parameters governing internal and external orientation. The same does not apply to the last step which operates a filtering based on the reprojection error and we must therefore correctly define the a priori accuracies for the measurements and the image coordinates. The former, as already mentioned, are obtained from the topographic survey, while the latter are more difficult to manage. In particular, the marker accuracy can assume values below 0.5 pixels if the identification procedure is rigorous, as in our case, and supported by automatic extraction algorithms. Therefore, we take its value to 0.1, verifying that the discrepancy between the error (m) and the accuracy (m) associated with the GCPs and CPs does not grow uncontrollably with the next optimization phase. As for the accuracy of tie points, we gradually reduce it by checking the convergence of Sigma0 to 1. As a rule, we always give more weight to markers than to tie points. After the calibration of these parameters, we perform a new optimization cycle and test that the value of Sigma0 tends to 1. If this does not happen, it is necessary to pay attention and, eventually, repeat the previous phases. In both projects, we achieve a value of 0.2 pixels (Fig. 2. 13).

The final optimization phase is removing points based on reprojection error. The latter is the distance between the point on the image where a 3D point can be projected and the original projection of that 3D point detected on the photo and used as a basis for the 3D point reconstruction procedure. The filter evaluates the maximum reprojection error in normalized units across all pictures where tie point is identified:

$$Max_i \, {|x_i' - x_i|}/{s_i} \qquad (3)$$

where x_i' is the point projection according to adjusted orientation parameters on the ith image in pixels, x_i is the measured point projection coordinates on the ith image in pixels and s_i is the image scale at which corresponding projection is evaluated on the ith image. High reprojection error usually indicates poor localization accuracy of the corresponding projections at the point matching step. It is also typical for false correlations. The threshold set for filtering in our applications is 0.3 pixels, not reached directly but by operating in successive cycles and selecting only 10 per cent of the tie points at a time. After the first cycle of this phase, we check that the error (m) of the markers does not exceed the accuracy (m). In this case, it is convenient to stop the process, re-evaluate and correct the a priori reliability of the image coordinates in the light of new data such as the RMS reprojection error. We then check that Sigma0 converges to 1. The selected lens coefficients are still those seen in the previous steps. If confluence does not occur, we can consider involving other coefficients and use additional corrections. At the end of all the cycles of the task we check the number of projections for each frame, the effective reduction of the iterations with the succession of the cycles, the survival of 15-20% of the original tie points and the possible presence of overfitting of the camera model. If no inconsistencies or anomalies emerge, the orientation process (so-called Structure from Motion - SfM) can be considered concluded.

For the sake of completeness, we analyse the correlation between the calibration coefficients of the camera [29, 30] (Fig. 2. 15). This is a good way to see if there is overfitting and may indicate that some of these parameters are not contributing substantially to representing the instrument. The set used in our applications is an 8-term, derived from the one originally formulated by Brown (1971). This comprises internal orientation parameters of main distance and principal point offset, as well as the three coefficients of radial and two of tangential distortion. The correlation between the radial coefficients is physiological and depends on the structure of the model itself; for this reason, we can neglect it. The decentring distortion ones are also strongly projectively coupled with the principal point offset. In general, this relationship increases with focal length, but as we use values for the latter that are closer to wide-angle lenses, the high correlation found in our designs is due to poorly converging image axes.

Close-range photogrammetry

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3931.85	0.0720308	1.00	-0.02	-0.07	-0.12	0.16	-0.17	-0.00	0.00
Cx	12.5561	0.206148		1.00	-0.03	0.00	0.00	-0.00	0.95	-0.04
Cy	-24.5021	0.0884523			1.00	-0.02	0.00	-0.00	-0.04	0.81
K1	-0.0259549	4.79627e-05				1.00	-0.96	0.91	-0.01	-0.02
K2	0.0429324	0.000143633					1.00	-0.98	0.00	0.00
K3	-0.0380892	0.000129836						1.00	-0.00	-0.00
P1	0.000376862	1.09816e-05							1.00	-0.05
P2	-0.0020551	4.28632e-06								1.00

UAV photogrammetry

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3038.81	0.116061	1.00	-0.02	-0.36	0.04	0.08	-0.07	-0.01	-0.21
Cx	-2.29594	0.0499155		1.00	-0.02	-0.02	0.02	-0.02	0.92	-0.00
Cy	-2.3232	0.0332944			1.00	-0.06	-0.01	0.01	-0.02	0.76
K1	0.000350022	7.9032e-05				1.00	-0.94	0.88	-0.03	-0.08
K2	-0.0121853	0.000325272					1.00	-0.98	0.02	0.01
K3	0.0138147	0.000412557						1.00	-0.03	-0.01
P1	-0.000347778	5.97391e-06							1.00	-0.00
P2	0.000100667	3.72344e-06								1.00

Fig. 2. 15. Correlation analysis between camera calibration coefficients.

This may be due to a few oblique frames alongside the orthogonal/nadiral ones. Again, the correlation is negligible.

We then move on to the dense image matching phase (often called Multi-View Stereo - MVS), based on the exterior and interior orientation parameters. Dense clouds are reconstructed from depth maps computed trough pairs of overlapping images, identified by their internal and relative external orientation parameters estimated using Bundle Block Adjustment. Multiple pairwise depth maps generated for each camera are merged into a combined depth map, employing excessive information in the overlapping regions to discard wrong depth measurements. The products are transformed into the partial dense point clouds, which are then merged into a final model with additional noise filtering step applied in the overlapping regions. The normals in the partial dense point clouds are calculated using plane fitting to the pixel neighbourhood in the combined depth maps, and the colours are sampled from the images. For every point in the final dense point cloud, the number of contributing maps is recorded and stored as a confidence value. This one will be used later to perform additional filtering. A list of parameters governing the procedure is explored below:

- quality affects the detail and accuracy of the reconstructed geometries as well as the processing time, depending on the amount of depth maps calculated. The high option, used in our applications, implies preliminary image size downscaling by a factor of 4 (2 by each side), a good compromise between model density and computational load;
- depth screening removes outliers from the cloud, due to aspects such as noisy or badly focused images, controlling them in the raw depth maps. This is done using a connected component strainer which operates on segmented depth maps based on the pixel values. We use a moderate filter to preserve the small, discernible details in the scene to be reconstructed;
- the process allows RGB information to be associated with individual points;
- the last option of fundamental importance is the calculation of point confidence, which counts how many depth maps are generated for each point, so that further filtering can be performed.

Once the dense cloud has been reconstructed, we proceed to edit it to remove the noise. In addition to the interactive intervention, which is useful for deleting badly located elements, we filter according to the number of depth maps per point. The results of this operation depend largely on the pattern of capturing frames. The algorithm is based on a non-linear selection scale ranging from 0 to 255, where lower values indicate few depth maps involved in the reconstruction of the 3D position of the point. Unfortunately, we do not have enough information to understand its working in a rigorous way, and therefore we rely on the indications provided by the developers, according to which the relevant part of the noise belongs to the range 1-5. This last operation closes the photogrammetric process. The overall dense cloud resulting from the combination of the two projects has a density of 3 mm. Table 2. 3 summarizes the main steps of the whole application.

Low-level data integration
The advantage of integrating different techniques and technologies is undeniable, even considering the difficulties involved in implementing non-standardized workflows that are still subject to experimentation. What is challenging is to assess how much this procedure can help in qualitative and economic terms to achieve a specif-

Table 2. 3. Summary of the main parameters and indicators of the SfM process.

	Close-range	**UAV**
	Structure from Motion - structure estimation	
Accuracy	High	High
Key point limit	60,000	60,000
Tie point limit	0	0
Estimated tie points	563,435	645,235
	Structure from Motion - structure optimization	
Camera model	8 parameters	8 parameters
GCPs	9	8
CPs	7	6
Rec. uncertainty limit	10	10
Projection accuracy limit	2	4
Reprojection error limit	0.3 pix	0.3 pix
Remaining tie points	85,564	92,840
Final Sigma0	0.90	0.82
RMS rep. error	0.20 pix	0.21 pix
Max rep. error	0.78 pix	0.84 pix
Mean key point size	1.36 pix	1.54 pix
Average GSD	1.19 mm/pix	5.93 mm/pix
RMS GCP error	5.92 mm	9.91 mm
RMS CP error	8.37 mm	14.54 mm

ic purpose. In this regard, as part of the activities carried out for the case study, we test the combination of image and range-based data to investigate possible degradation phenomena affecting the asset, according to the owner's requests.

Laser scanner systems (terrestrial and phase-shift in our application) allow the analysis of deformations of structural elements and the localization of cracks, but not the accurate estimation of their thicknesses. This shortcoming can be remedied by rigorous photogrammetric reconstruction (close-range with mirrorless camera). However, it remains to be seen whether the intersection of the pipelines returns a reliable model than those derived from distinct flows.

The literature is full of examples where data from the two techniques are combined. These are almost always high-level integrations, where the processing streams are kept separate until the results are obtained and merged into a single final model. One of the most common solutions involves using GCP coordinates to record point clouds in a shared reference system (defined according to requirements). These coordinates can be derived from superordinate sources, such as a topographic survey (see the case study) or extracted from the global laser cloud after accurate registration of its stations. A variant of the illustrated procedure employs a derivative of the Iterative Closest Point (ICP) algorithm (basic form, with random point selection on the moving entity and no geometric constraint on the rigid transformation) to optimize the first registration via GCPs, fixing the laser cloud as a reference object.

As a possible alternative, we propose a low-level integration process. Structured point clouds of outdoor areas (single scans in E57 file), derived from the TLS survey, are used, after frame orientation, to optimize the depth maps needed to generate the photogrammetric dense model. To date, there is no commercial software that allows this to be done automatically. Therefore, we introduce a script in Python that makes it possible to locate the scans in a photogrammetric project while preserving the information from the TLS registration.

The experimentation is conducted in the Agisoft Metashape Professional environment, software capable of managing structured clouds from laser scanner systems. According to the conventional approach, the scans should be imported together with the photographic set in a single group (obviously separating the calibration parameters), and then proceed with the orientation. The clouds are converted into spherical equirectangular images (if they have RGB data, as in the case study) or intensity maps and treated to search for key and tie points. During the dense cloud generation, photogrammetric depth maps are merged with the information coming from the laser scanner.

Our proposal introduces a variation: the scans are not used in the orientation phase, but only for the calculation of depth maps. There are two reasons for this:

- although the software is perfectly capable of handling separate calibration groups, these make it more difficult to control and interpret the parameters governing filtering and alignment optimization operations;

- the registration of scans from a stationary system (such as the TLS we use) is generally more accurate than the orientation of spherical images, especially when supported by data from a topographic survey.

These assumptions led us to develop a solution that aims to preserve the accuracy of TLS cloud registration while providing greater control over the photogrammetric process, without sacrificing the advantages of integration to improve both the reliability and the graphical rendering of the final dense cloud. Every application needs its own benchmark. We limit our analysis to the external wall curtain of the ground floor, setting up three pairs of point clouds for comparison. In these ones the reference element is always represented by the TLS cloud while the one matched is respectively:

1. the dense point cloud resulting from the traditional photogrammetric process, geolocated using GCPs;
2. the photogrammetric dense cloud, geolocated using GCPs and an ICP-derived algorithm against the global TLS model;
3. the cloud produced by the integration of photogrammetry and TLS.

More specifically, we only use the close-range dataset, processed according to the procedures outlined in the related section. The algorithm used for verification is the multiscale model-to-model cloud comparison (M3C2) [31-34]. Our core points correspond to the reference entity and for the calculation of their normals we use a sphere with a radius of 5 cm, a dimension compatible with the architectural scale and the characteristic noise of a TLS cloud. This last operation is performed in advance (in MeshLab 2022.02) so that the same set of vectors can be employed for the three pairs. The projection scale, represented by the base diameter of the cylinder applied to circumscribe the distance calculation area, is also set to 5 cm. As an initial registration error, we use the one resulting from the fine location of the TLS stations, equal to 1.3 mm, to check if the deviations between homologous models are significant. We also note that the photogrammetric clouds have very similar densities, allowing us to overlook this factor when discussing the results.

Analysing the distance histograms (Fig. 2. 16), we can see that pair 1, registered using only GCP coordinates, shows the greatest dispersion, with a main peak at 1 mm (approximately) and a secondary peak at -8 mm (M3C2 provides oriented distances). Pair 2, which is also affected by an ICP-derived optimization, shows a more compact histogram horizontally, indicating the benefit of this process. This approach, however, tries to reduce the distance between the compared objects, somewhat overshadowing the position of the GCPs used for alignment. The best result is observed, in any case, in pair 3, where the peak at the 1 mm value undergoes a growth, while the one at -8 mm is flattened, a sign that the contribution deriving from the TLS depth maps succeeds in enhancing the processing of the dense cloud. In general, this improvement is of the order of 4-5 mm, which in

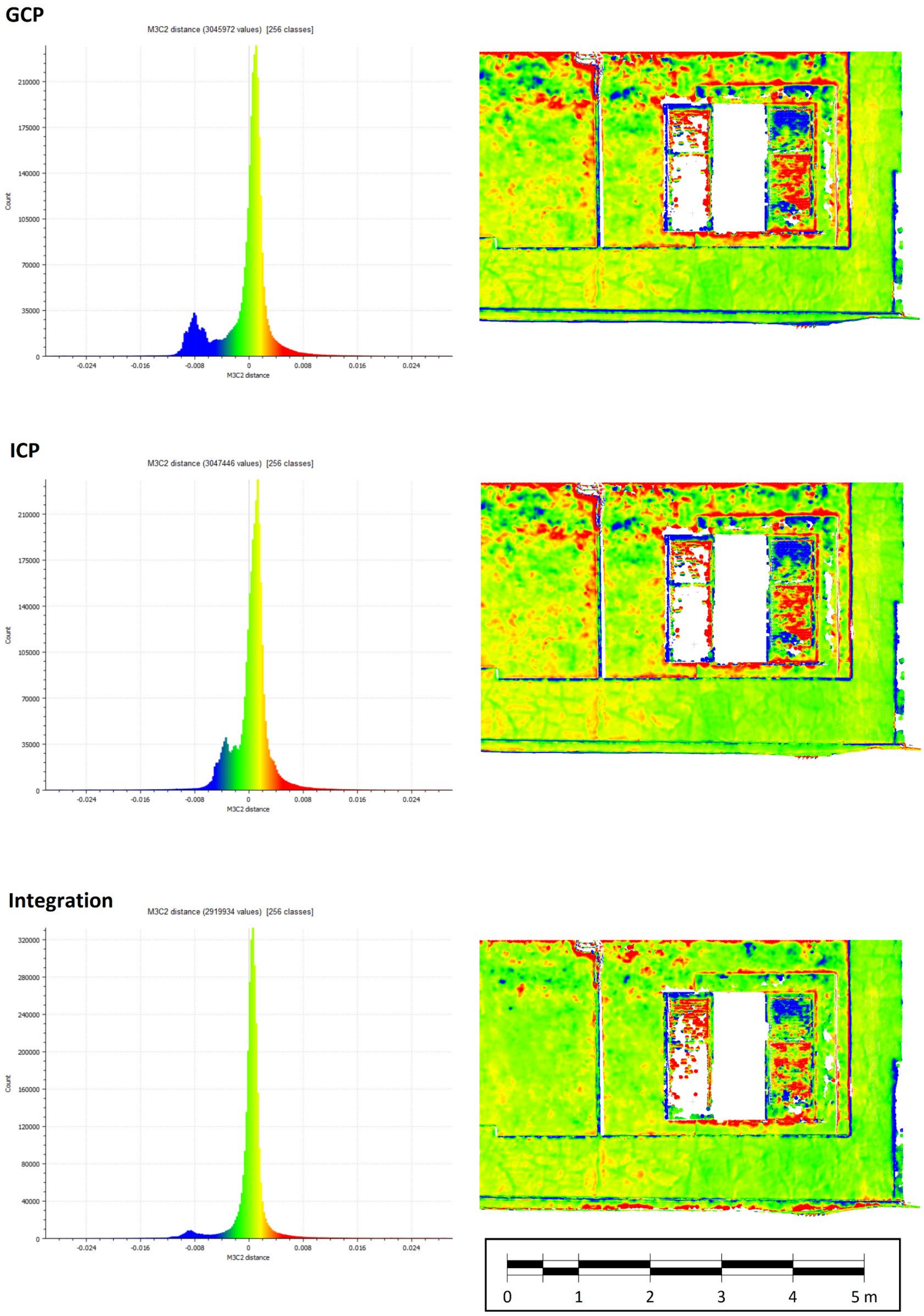

Fig. 2. 16. Analysis of discrepancies between TLS cloud and photogrammetric models**.**

most architectural applications would not justify the use of an additional laser survey to optimize photogrammetry. However, the results are encouraging and could be exploited to develop integrated sensor-level systems that can provide maximum synergy between the two detection techniques.

Object recognition

Object recognition and the extraction of relational and semantic information are central themes of Scan-to-BIM applications, which have been extensively investigated in the literature. The methods and tools used to perform these operations are related to several factors, such as the complexity of the structure, the required levels of development, the data acquisition techniques, and others.

From these basic remarks, many approaches have been proposed in recent years that, in an automatic or semi-automatic way, support the operator in this process. All of them, however, are based on one assumption: the properties (geometric and non-geometric) of the investigated object used for recognition and classification, must be observable in a dataset constructed from some form of digital survey.

Unfortunately, this is not always possible or would require an investment of resources and time that would not justify the methodology applied. In a completely plastered load-bearing wall, for example, any stratifications, indicated by variations in materials or equipment techniques, are not directly observable. In these contexts, the best solution is to cross-reference the limited data available from the survey with data from other, almost always non-digital sources, such as plans, permits, deeds, etc. An interactive approach, with manual identification of objects, is therefore required [35].

This is the situation in the case study, where the client explicitly requested a chronological reconstruction of the transformations undergone by the building block. However, the structure underwent a major renovation (about 20 years ago), which makes it difficult if not impossible to observe many aspects that could corroborate the reconstruction.

Fortunately, the owners themselves provided us with all the paper documentation in his possession, also containing photographs of the many activities that have affected the structure, to be crossed with the data of the digital survey to accurately reconstruct the evolution of the building.

Stratification identification

The building block is currently divided into two units, owned by the brothers di Filippo Maria (most of the ground floor with its share of the basement) and di Filippo Rocco (upper floors, two rooms on the ground floor and basement).

There is no information on the original nucleus of the building, located at the intersection of *Via Marconi* and *Vicolo Capuano*, which would be useful to place its construction in time. The first document that provides relevant data for dating it is a deed of sale between family members (*atto di compravendita tra congiunti per notaio Alfredo Palmieri del 24 luglio 1923 - Numero Repertorio atti tra vivi n. 36*) with which the father, di Filippo Andrea, sells to his son, di Filippo Antonio, the “included of houses, with behind garden and basement, below the neighbouring building of Maria De Filippis, received from Giacinto Capuano, with instrument for notary Rescigno of *Nocera Inferiore* of 24 August 1894 and for notary Giuseppe Di Filippo of *Siano* of 22 May 1896, bordering on *Corso Plebiscito* (now *Via Marconi*), *Vicolo Capuano*, Maria De Filippis and others, recorded in the *Siano* Land Registry as a building under Article 711, taxable at Lire 28.50 and the garden under Article 711.” Also in the deed, on page 5, we read: “For clarification ... it is explained that both ... and the structures, on the corner of *Vicolo Capuano* and *Corso Plebiscito* ... are excluded from this sale, as is the clearing behind the structures ... The vendor reserves the right to erect buildings ... in the clearing, up to the floor I say the level of the floor of the room still existing on the abovementioned constructions”.

It can be deduced that all the rooms along *Via Marconi* were already there in the years 1894-1896 (ground floor, first floor and basement, obviously built in an even earlier period). From the analysis of the TLS data, it can also be deduced that the rooms transferred by deed of 1923 and those already owned by the family were built by distinct workers, probably at different times: in fact, the former have vertical wall elements with an average thickness (when finished) lower than the others, both on the ground floor and on the first floor. In addition, the inter-floor heights are considerably different and the floors themselves are made of iron and brick elements in the first case and of cast-in-place concrete in the second.

The first extension of the above-mentioned structure was carried out in 1955, as evidenced by a building permit (*Autorizzazione alla costruzione*), the application for which dates to 28 December 1954, with a favourable opinion of the Municipality of *Siano* dated 21 March 1955. This document authorizes di Filippo Gerardo (Antonio’s son) to build a room on the ground floor and a pavement along *Vicolo Capuano*. The analysis of the TLS data, which shows a characteristic thickness of the vertical elements for this room, confirms that it is a homogeneous addition. To the same period can be traced the construction of toilets, kitchen, and external staircase for access to the first floor, replacing the wooden one, removed for the edification of the ground floor rooms.

A second extension was carried out in 1960, with planning permission (*Licenza di sopraelevazione*) protocol n° 3636 of 30 September 1960, again in favour of di Filippo Gerardo, comprising two rooms and toilets on the first floor, along *Vicolo Capuano*, in correspondence with the lower ones. At the same time, on the ground floor, a brick roof was built to cover part of the remaining outdoor space in order to connect the existing ground floor rooms and extend the entrance area to the upper rooms, protecting the accesses through an iron and glass veranda. The access area to the basement was also paved with concrete. The modifications are confirmed by morphological and dimensional analysis on TLS data.

From 1986 to 1998, no further work was carried out on the building, although the owner, di Filippo Gerardo, had obtained a permit from the municipality for an extension and superelevation (*Concessione edilizia, Registro costruzioni n° 2882, prot. n° 150 del 31 ottobre 1986*), due to his death. The heirs, following the succession by law, obtained the re-approval and the transfer of the title (*Concessione edilizia, Registro costruzioni n° 208, prot. n° 2885 del 3 dicembre 1992*), a variant for supervening modifications of the general town plan (*Concessione edilizia, Registro costruzioni n° 21, prot. n° 4021 del 15 febbraio 1993*) and an extension (*Concessione edilizia, Registro costruzioni n° 99, prot. n° 4021 del 6 ottobre 1995*).

Following the discovery of the will by the deceased di Filippo Gerardo (*Atto notarile, rep. N° 88728 del 31 gennaio 1996 per notaio Squillante*), part of the ground floor was attributed to di Filippo Maria and the remainder to di Filippo Rocco (remember the division of the cellar), who thus obtained a change of permission (*Concessione edilizia, Registro costruzioni n° 89, prot. n° 4021 del 21 luglio 1997*). The authorized work consisted in the demolition of the iron and glass veranda on the first floor and the reconstruction of the same in masonry with a concrete slab roof, as well as the construction of an attic on the second floor.

On 15 April 1999 the owner, di Filippo Rocco, began renovation work (edification of a roof space) and extraordinary maintenance interventions on the first floor (Fig. 2. 17), consisting of consolidation of the load-bearing structures, refurbishment of all the installations, replacement of fixtures and floors, restoration of the facades and painting (*Concessione edilizia, Registro costruzioni n° 13, prot. n° 4740 del 30 marzo 1999*). These works were covered by the incentives provided for in Article 1, Law 449 of 27 December 1997 (deduction of 41%). These operations and the superelevation were completed on 23 March 2000.

With *Dichiarazione di inizio attività* (i.e., a planning permission), prot. n°. 7674 of 15 May 2009, the owner di Filippo Maria carried out extraordinary maintenance work on the three rooms on the ground floor along *Vicolo Capuano*, taking advantage of the same incentives.

Following an equal procedure (*Dichiarazione di inizio attività, prot. n° 4000 del 30 marzo 2012*), both owners carried out extraordinary maintenance work on the ground floor for 2 rooms on *Via Marconi* (di Filippo Rocco) and for a veranda, bathroom, and kitchen (di Filippo Maria), again taking advantage of the abovementioned incentives (Fig. 2. 18).

The last intervention consisted in the construction of a photovoltaic plant on the pitched roof (Communication to the Municipality of *Siano*, prot. n° 976/UTC of 23 January 2012). The 2.94 kW system came into operation on 17 May 2012 and benefits from the incentive tariffs set out in the *Decreto Ministeriale* (administrative document) of 5 May 2011.

All this information, cross-referenced and validated through the data derived from the digital survey, is used for the interactive identification of the structural elements and their classification in relation to the indicative period of construction.

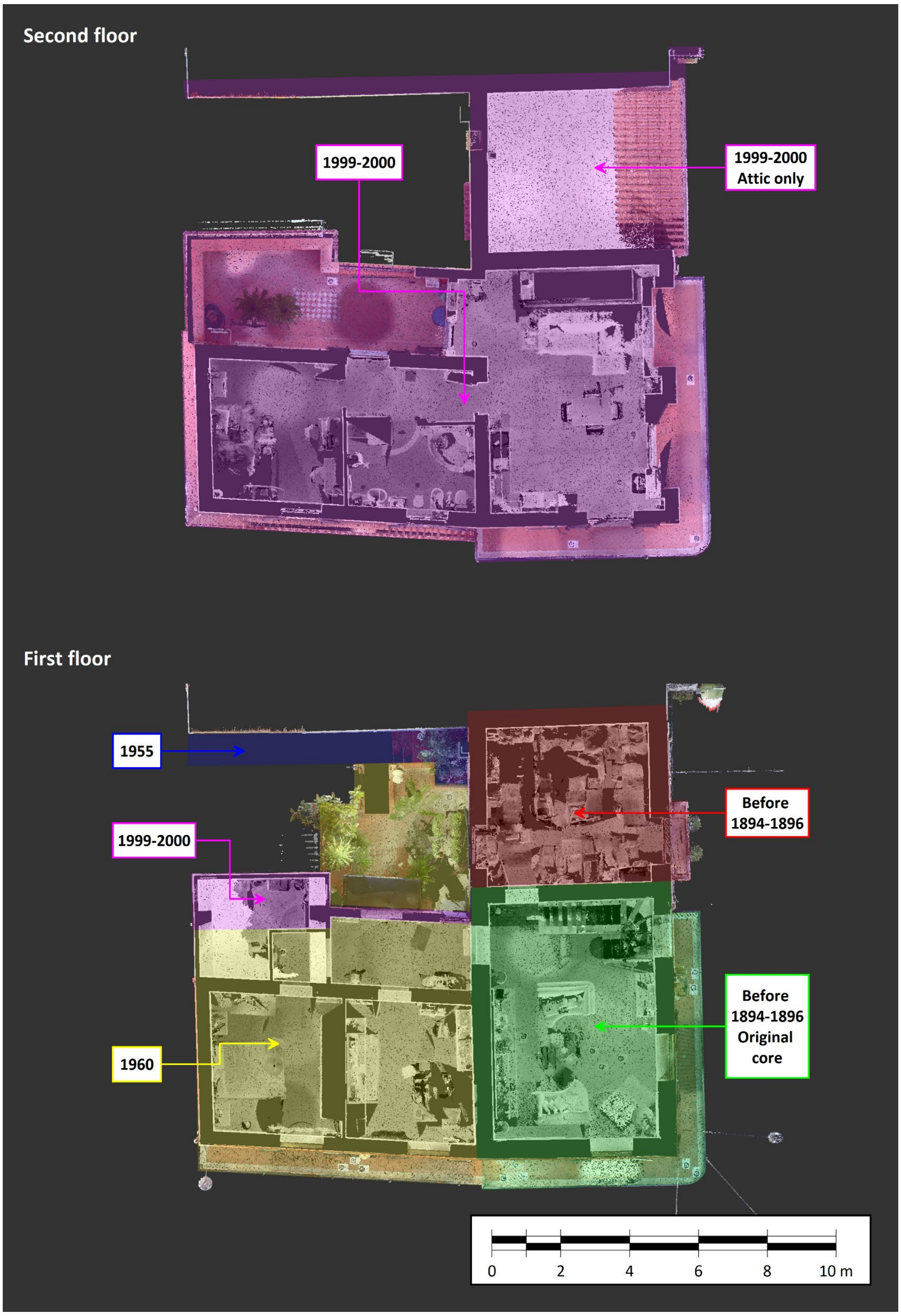

Fig. 2. 17. Chronological stratification of the first and second floors.

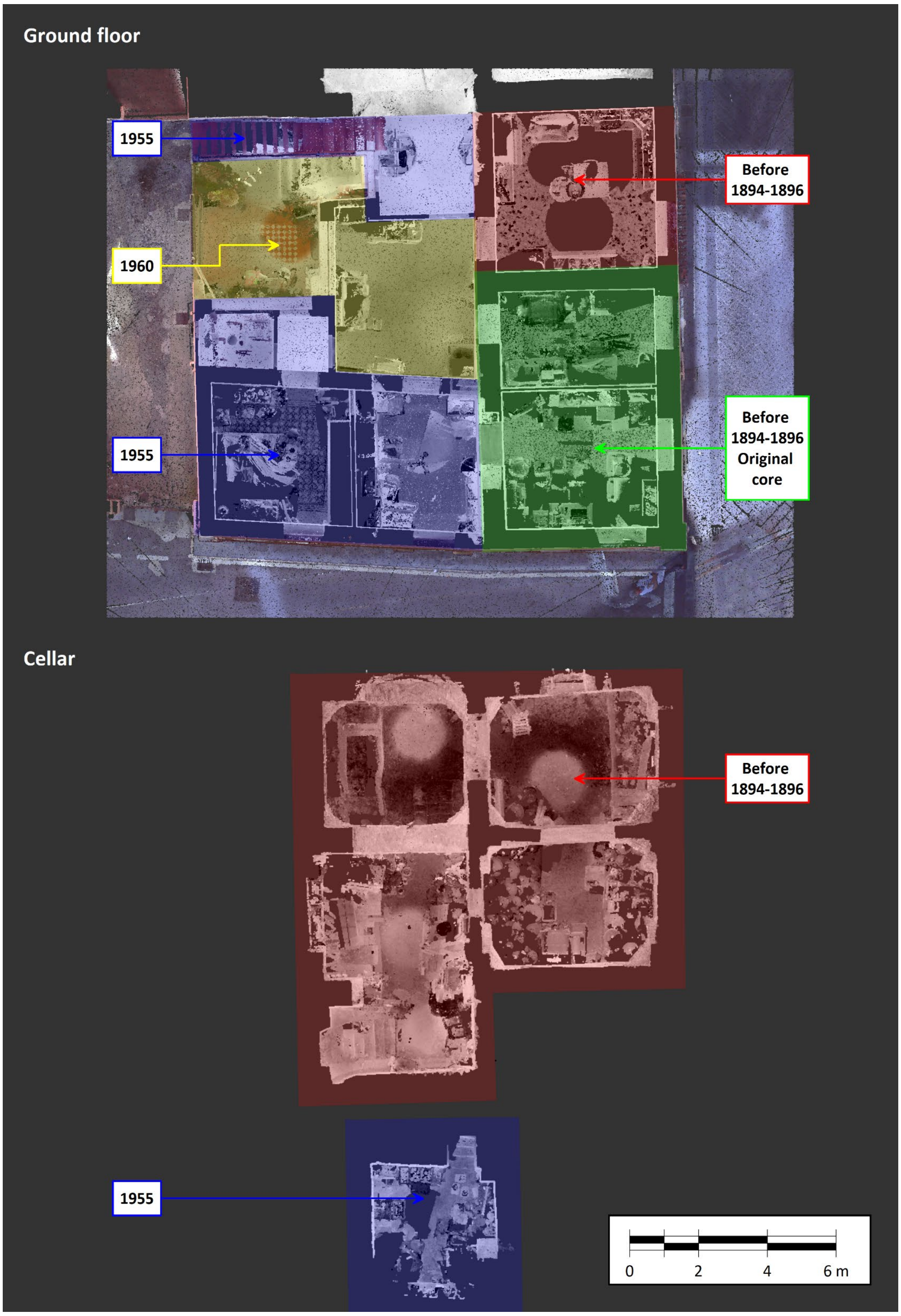

Fig. 2. 18. Chronological stratification of the ground floor and cellar.

The process greatly simplifies the modelling phase in the BIM platform, speeding up the recognition of the distinctive features of the objects that make up the virtualization and the subsequent parameterization. In addition, the same information flows into a tool that is originally designed to differentiate edification phases but has been adapted to visualize and isolate the components of the structure in relation to the construction period. Appendix C contains all the main documents referred to in this paragraph.

BIM modelling

When applying the BIM methodology to the documentation of the existing heritage, we must define two fundamental aspects: the modelling approach that we will use and the level of reliability (geometric and non-geometric) of the product.

Starting from the first point, although the software platforms are not exactly optimized for the virtualization of existing buildings (especially if they are built using traditional techniques and consist of elements that are difficult to standardize), for our applications we have nevertheless opted for these solutions so as not to give up the undisputed advantages of parameterizing the topological and relational attributes of the objects.

Among the various platforms available on the market, we decided to work with Autodesk Revit (version 2022) because, compared to other solutions, it guarantees optimal management of the data resulting from the acquisition and processing phases, without having to resort to extensions or external software.

Starting from the client's requests, the architectural model will have to allow the extrapolation of graphical outputs on a scale of 1:50, compatibly with an executive design level, preserving the differences among elements that can be traced back to the same family.

In accordance with these assumptions, it will be necessary to verify that the discrepancies between the source-based and reality-based models are appropriate. This chapter is narrowed to the methodological aspect, focusing primarily on the general issue of reliability of data and leaving questions such as accuracy and uncertainty, particularly with respect to geometric attributes, to the next chapter.

As far as possible we use system families for the basic elements like walls, floors, ceilings, and stairs (Fig. 2. 19). These ones best handle the host functions for other categories, generally loadable, such as windows, doors, and furniture. In special cases, we proceed instead with the creation of custom families (trying to avoid in-place components and masses). They provide greater versatility in parameterization and can be exported and reused in other projects. In-place components are instead more difficult to program, e.g., if you want to extract dimensional variables or apply materials, forcing the operator to work on individual instances. In addition, they are bound to the specific project. Masses, on the other hand, are very good for virtualizing complex volumes but lose many advantages

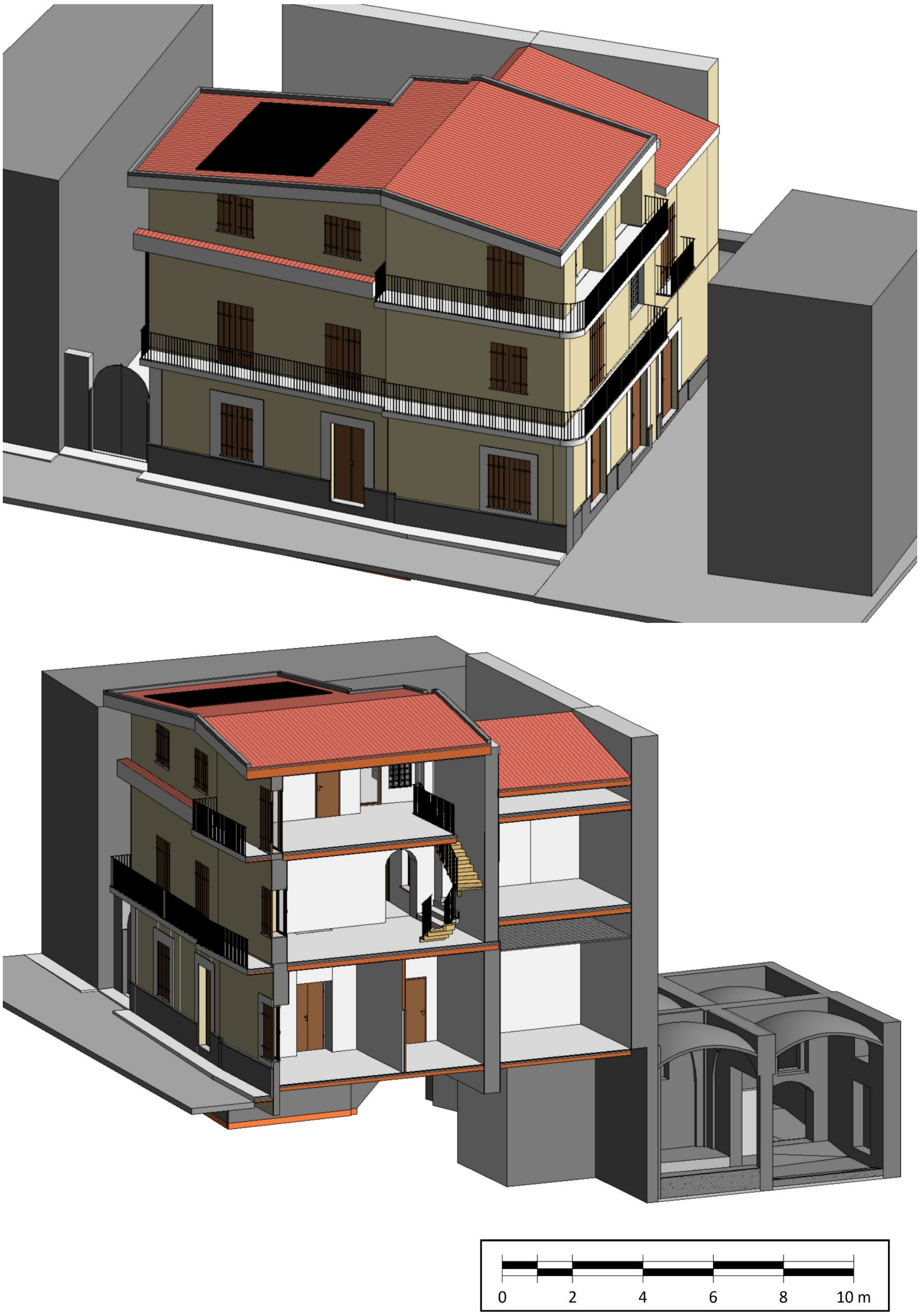

Fig. 2. 19. Axonometric view and cross-section of the BIM model.

related to parameterization, moving far away from the philosophy behind BIM. If it is necessary, the geometries of the freeform objects should be managed externally, possibly with meshes, and then linked to the model. With complex shapes, the forming effort is no longer compatible with the purposes of our applications (and more generally of a BIM). In these cases, we simplify the element, using external links for proper description.

We follow this approach not only for the documentation of the silhouette but also for deformations, materials, degradation phenomena and damages, with a process that, starting from the identification of flat surfaces that approximate the real elements, produce digital elevation models (DEM) or orthophotos calculated with respect to the same surfaces, representing graphically (and analytically) the discrepancies between reality and abstraction or a specific object characterization. In these cases, the BIM model acts as a collector, making it possible to systematize all the information content and at the same time guaranteeing the manageability of the file thanks to external links that replace laborious local modelling.

This type of integration between the 3D virtualization and 2D outputs should not frighten us, as proper documentation, consistent with the objectives, makes use of the tools that best describe the phenomena of interest, without any a priori exclusion.

Semantic classing

The identification and description of the relationships between the objects of a BIM model also have a strong impact on its representation. There is not, in fact, a codified protocol to perform these operations, especially if we refer to existing buildings. From a theoretical point of view, the structural organism can be analysed and decomposed in relation to many attributes (structural, compositional, functional, stratigraphic, etc.) and at different levels (single elements, their combinations, construction bodies), according to the applications of the digital product.

Keeping in mind the owner’s requests, who asked us to clarify all the interventions and transformations undergone by the asset, we opted for a stratigraphic criterion, identifying a scheme with 5 descending semantic levels: building (I), stratigraphic units (II), classes of technological units (III), technological units (IV), classes of technical elements (V) (Fig. 2. 20, Table 2. 4).

The stratigraphic units are directly related to the interventions carried out on the structure, identified thanks to the paper documentation provided by the owner himself, even including original plans and purchase receipts of the building materials, useful to characterize the properties associated with the digital objects.

To define the technological unit classes and the levels below we consider instead the standards UNI 8290-1:1981 + A112:1983 and UNI 10838:1999, which are still the reference for planned maintenance, especially for existing buildings, and from which guidelines for action have been derived by many regions of Italy. Following these standards, elements are catalogued in relation to functional and technological aspects and identified by means of numeric code associated with the objects as a parameter.

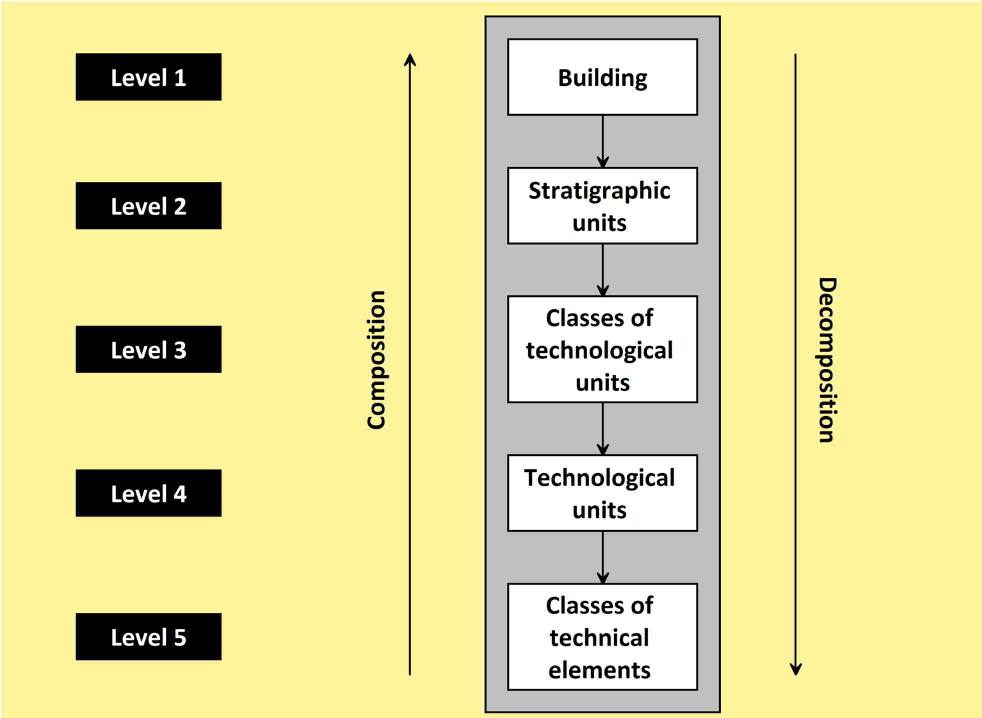

Fig. 2. 20. Semantic classing scheme of objects in the BIM model (author's elaboration).

Reliability of data sources

The issue of reliability and traceability of the information content that flows into a BIM model is only marginally addressed in technical regulations. To tell the truth, in the literature we can find some attempts to define a reference framework, almost always limited to specific types of content and completely detached from the guidelines for the correct management of information flows and model creation contained in national and international norms.

The UNI 11337 standards, in parts 4 and 5, provide useful guidance on the coordination, progress, verification and approval of information content in relation to the chosen Common Data Environment. The most interesting aspect for the purposes of an in-depth examination of reliability is represented by the verification levels which, together with the other three points mentioned above, outlines the interchange flow.

If we want to refer to the construction of the general architectural model for the case study, we are interested in level 1 of formal internal verification which follows the elaboration, and level 2 of substantial verification which follows the sharing and concerns the link with other models. We intend to take advantage of this framework to include our proposal, modifying level 1 which is no longer just formal but substantial for the individual virtualization and is aimed at ascertaining the readability, traceability, and consistency of the information.

Table 2. 4. Extract from the classification scheme of UNI 8290-1:1981 + A112:1983.

Classes of technological units	Technological units	Classes of technical elements
Load-bearing structures (1)	Foundation structures (1.1)	Direct foundation structures (1.1.1)
		Indirect foundation structures (1.1.2)
	Elevation structures (1.2)	Vertical elevation structures (1.2.1)
		Horizontal and inclined elevation structures (1.2.2)
		Spatial elevation structures (1.2.3)
	Containment structures (1.3)	Vertical containment structures (1.3.1)
		Horizontal containment structures (1.3.2)
Closure (2)	Vertical closure (2.1)	Vertical perimeter walls (2.1.1)
		Vertical external frames (2.1.2)
	Lower horizontal closure (2.2)	Ground slabs (2.2.1)
		Horizontal frames (2.2.2)
	Horizontal closure on external spaces (2.3)	Slabs on open spaces (2.3.1)
	Upper closure (2.4)	Roofs (2.4.1)
		horizontal external frames (2.4.2)
Internal partition (3)	Vertical internal partition (3.1)	Vertical internal walls (3.1.1)
		Vertical internal frames (3.1.2)
		Protection elements (3.1.3)
	Horizontal internal partition (3.2)	Slabs (3.2.1)
		Mezzanines (3.2.2)
		Horizontal internal frames (3.2.3)
	Inclined internal partition (3.3)	Internal stairs (3.3.1)
		Internal ramps (3.3.2)
External partition (4)	Vertical external partition (4.1)	Protection elements (4.1.1)
		Separation elements (4.1.2)
	Horizontal external partition (4.2)	Balconies and lodges (4.2.1)
		Footbridges (4.2.2)
	Inclined external partition (4.3)	External stairs (4.3.1)
		External ramps (4.3.2)

Having clarified when to carry out the verification, it remains to define how to quantify reliability of the individual objects that make up the model. Once again, we use a tool that is already present in the Italian regulations: the levels of knowledge, which measure the degree of learning about a facility, achieved in relation to structural analysis methods, economic resources, and time available. They are described by the Technical Standards for Construction (*NTC 2018*) and the relevant circular but have been present in state legislation for many years. Our proposal introduces three main innovations compared to what is already laid down in the regulation (Table 2. 5):

- the presence of a level 0 representing the absence of information;
- the provision of a single classification system that does not depend on construction techniques;
- the separation of levels for the properties and characteristics investigated for individual objects.

Moreover, we replace the term knowledge with reliability in order to avoid ambiguity with Italian acronyms, that coincide with those of the levels of coordination in the interchange flow, a sign that homogeneity is still lacking in the national regulations of the AEC sector. The informative contents dealt with are referred to the single objects: geometric, structural, and material. For the first ones, as anticipat-

Table 2. 5. Scheme for identifying reliability levels of information content.

Level of reliability (LR)	Geometry (G)	Structural details (S)	Material properties (M)
LR0 Absent	Unknown geometry, derived from assumptions by analogy or historical images and documents.	Unknown construction techniques, derived by analogy with other elements or from images and documents.	Unknown materials, deducible from historical images or documents.
LR1 Limited	Geometry assessed from the original plans or from quick surveys using traditional techniques.	Simulated design according to the standards of the time and limited site investigations.	Values usual for construction practice at the time and limited in situ testing.
LR2 Extended	The geometry is known thanks to surveys with digital technology, but not certified.	Incomplete design drawings with limited in-situ investigations; alternatively extensive in-situ investigations.	From original design specifications or original test certificates, with limited in-situ testing; alternatively, from extensive in-situ testing.
LR3 Exhaustive	The geometry is known thanks to digitally controlled surveys that are certified for accuracy.	Comprehensive design drawings with limited in situ investigations; alternatively comprehensive in situ investigations.	From the original test certificates or original design specifications, with extensive on-site testing; alternatively, from extensive on-site testing.

ed, an in-depth study is required because it is not sufficient to clarify how the building is detected, but it is also necessary to consider what the uncertainties on the measurements are.

Preparation of the modelling phase
A fundamental requirement for the application of the Scan-to-BIM technique is the ability to better handle the point cloud derived from the survey inside the modelling software. The Autodesk Revit platform uses an external tool to manage this data, named Autodesk ReCap 2022. As we will see, this resource is used within the workflow not only as a bridge between Revit and the processing software, but also to optimize the reality-based model.

The first aspect taken into consideration is the density of the cloud. Although the survey data allow us to reach high resolutions, there are heavy slowdowns in the display and the solution is a decimation with a spacing of 5 mm, enough distance between points to preserve both the details and the lightness of the file. Only when strictly necessary to describe elements or phenomena at a greater scale, partial models are produced at higher resolution.

The overall cloud is then divided into regions, interactively, consistent with the stratigraphic units recognized through analysis of paper documentation provided by the owner (Fig. 2. 21).

2.6 Remarks and conclusions

Three-dimensional digitization has become a central tool for the systematic documentation of existing heritage, a process that is conventionally employed but lacks a general codification. While on the one hand we see a progressive decrease of costs, both instrumental and operational, to produce a reality-based virtualization, on the other hand we see a growing demand for models that can be used not only to describe the geometries of the building but also to manage it throughout its life cycle.

The philosophy behind BIM is clearly a response to this need, a valuable resource to support decision-making and a substantial alternative to conventional approaches to documentation, based on CAD drawings that essentially only delve into geometric attributes.

Although BIM is now widely accepted in the design and execution of new buildings, with increasing interest in advanced life cycle phases, its application to heritage documentation remains a challenge, with the creation of as-built/as-is models requiring a significant outflow of resources. In most cases this is done by fitting parametric objects to the point cloud obtained through surveying techniques, a highly interactive process. This task becomes particularly burdensome if the building is full of unique elements that are difficult to standardise. While the literature focuses heavily on the development of modelling approaches, we can observe the lack of solutions to assess geometric accuracy, traceability of information sources

Fig. 2. 21. Axonometric view and cross-section of the integrated point cloud.

and their reliability, all fundamental aspects to ensure the reusability of the model over time. These difficulties can be summarised as the need to define and find the right compromise between the virtual fidelity of a reality-based virtualization and the flexibility and semantic richness of parametric modelling, which is useful for the management part. An ideal product should possess both properties, but in practice its realisation is hardly ever sustainable, both operationally and economically, especially in the private construction sector.

The proposal developed in the previous paragraphs is based on a critical approach to BIM modelling, where the needs of the specific documentation guide the choice of the most suitable tool to describe and represent the information. Profiling all data in a 3D digital environment is perhaps not the most effective option. There are some tasks such as surface mapping (materials, degradation, etc.) that cannot be solved without 2D outputs, such as orthophotos and DEMs, both for the sake of completeness and for ease of management of time-delayed analyses. Unfortunately, these products are not always easy to interrogate in a parametric space, nor can they be used as direct support for the modelling itself. Despite the current shortcomings, this approach appears to be the most profitable solution in terms of resource optimisation and future research developments will presumably be oriented in this direction, to achieve an appropriate level of correlation between 3D model and 2D outputs.

Our experience is complemented by the provision of a semantic classification system for parametric objects, compatible with current technical building regulations, and a solution for tracking the reliability of the data implemented in the model. Both are fundamental aspects for ensuring the upgradeability of BIM products, but are marginally analysed in the literature, which too often focuses only on geometric attributes, employing parametric virtualisation as an alternative form of representation of survey data. Our proposal goes against this trend in order to mitigate this tendency and focus attention on those aspects that can contribute substantially to the diffusion of the methodology.

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3 Traceability in BIM processes for existing structures

3.1 The uncertainties of geometric attributes

The reusability of information content throughout the building life cycle, ascribable to the functional aspects of BIM, is a main issue, however little addressed in literature and marginally covered by technical regulations [1-3]. One of the cornerstones of BIM is precisely to ensure the availability and portability of data which, against a greater initial investment for the construction of the model, will offer a multidisciplinary and integrated tool to support all possible operations on the building. The issue is further complicated in the case of Cultural Heritage or existing structures where the information process starts directly from the execution stage (management and maintenance phases) and provides, through reverse engineering methodology, an Asset Information Model.

It is therefore essential to keep track of accuracy for this content, in relation to the attributes of all the objects that make up the virtualization [4-7]. The number of articles on BIM for existing buildings and quality assessment is limited. Identifying the starting point is not difficult [8]; the focus of this paper is mainly on the detection and classification of geometric modelling errors, or the ones appearing during the data collection or post-processing phase.

Some researchers conducting Scan-to-BIM case studies already mention deviation analysis of the assembled BIM against the reference point cloud as a part of their methodology [9, 10]. If such assessment is executed, it is often done with the use of commercial BIM plugins to get an idea of the general deviations of certain selected surfaces by using a gradient colour map. Other frameworks, such as the Level of Reliability, are not limited to the analysis of the geometric attributes of the objects but also consider the ontological correspondence of the same to reality [11, 12]. However, an in-depth look at the nature of the uncertainty components contributing to the dimensional approximation is lacking here.

Among the building documentation specifications, the Level of Accuracy (LOA) from the USIBD [13], not only gives us a clear definition of Measured and Represented Accuracy, it also defines LOA classes. Suggested LOA ranges for precise standard and heritage building elements are available. Furthermore, the LOA guideline does not specify which methods should be used for estimating the accuracy, and for the integration of the quality assessment results in the BIM.

We can also find a marginal and very fragmented treatment in the technical norms, often not directly related to BIM, of which the best example is the German standard, with the 4 parts that make up DIN 18710 [14], however limited to the geometric accuracy of the survey phase.

Starting from a careful analysis of the state of the art related to these issues, our work proposes a possible approach to the statistical treatment of uncertainties linked to geometric attributes in case of Historic or Existing BIM, differentiating between the products of the survey and those of the subsequent parametric modelling. All this information is summarized in a label to be associated with the individual objects as a composed parameter, to guarantee the traceability of the survey and digitization processes from a geometric point of view, and the reusability of the model itself for future interventions on the structure.

3.2 A methodological proposal

The proposed methodology is divided into two distinct sections; the first focuses on assessing the quality of the survey operations that precede the BIM modelling in the case of existing structures (Fig. 3. 1), setting up a geometric database on which to define the single objects; the second describe the quality of the parametrization process and, as we shall see, may or may not be related to the previous operation.

Detected accuracy

We start by analysing the possible techniques used to define a common reference system for all virtualized elements, as also foreseen by the Exchange Information Requirements (EIR) of UNI EN ISO 19650 and the equivalent documents of the national technical standards [15]. The activity can refer to a global system, such as the topographic network, or to a local one, established for example with respect to a TLS station. The same evaluation can be of absolute type, when it involves the coordinates of specific points distributed in the scene, or of relative type, if it concerns the distances between these reference points.

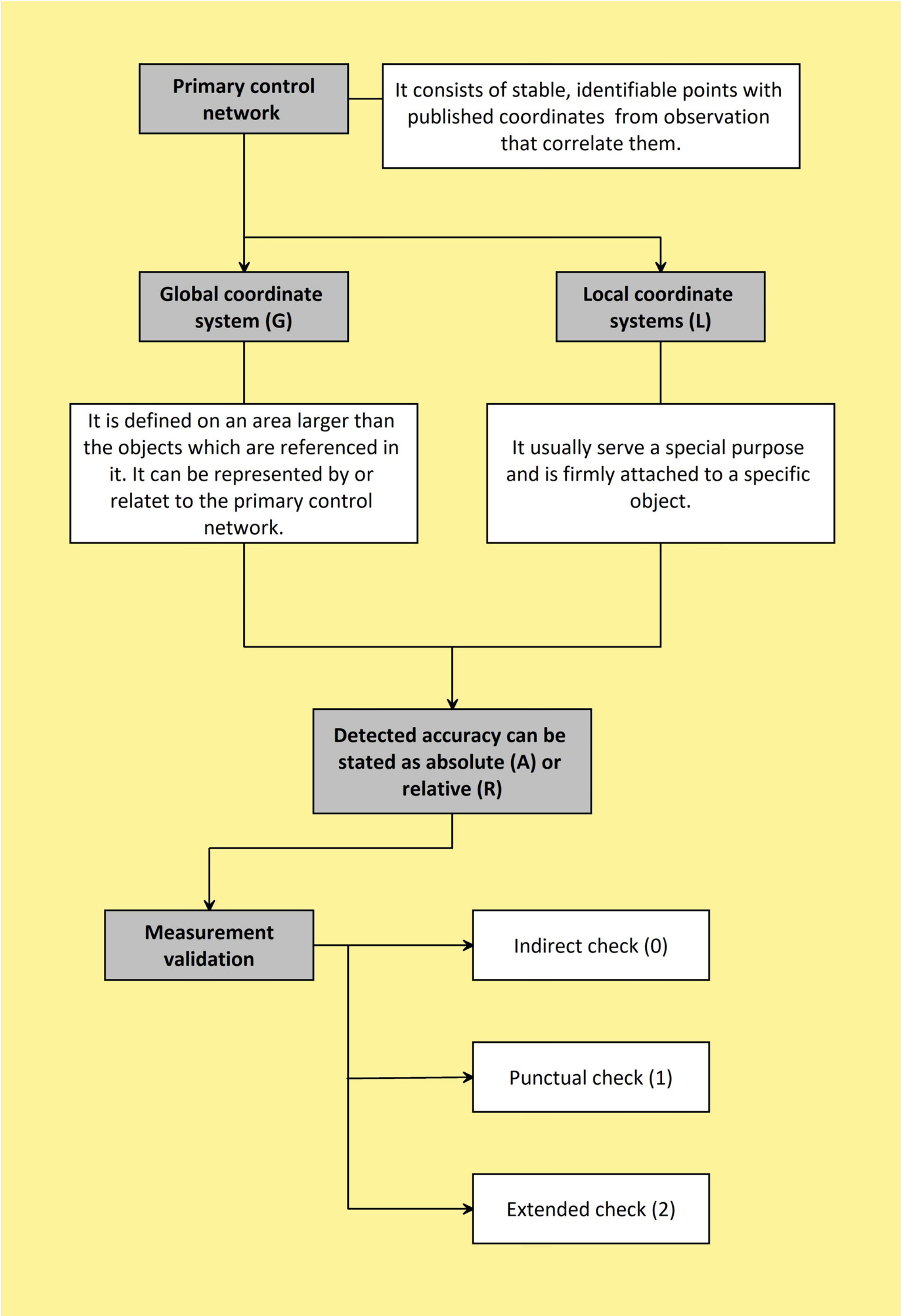

Fig. 3. 1. Framework for tracking the accuracy of survey operations (author's elaboration).

Subsequently, sources of uncertainty related to instrumentation, techniques, their integration and statistically describing their distributions are identified. This enables us to define a propagation law for them and to obtain a dispersion indicator or an interval that effectively summarize the accuracy of the survey.

However, locating sources of uncertainty and combining them are far from simple tasks. It is not possible to find at an unambiguous solution, and this depends largely on the detection techniques and how the raw data are transformed to obtain a reality-based model.

Given the impossibility of enumerating and describing all the combinations, we proceed with an inductive approach, starting from a practical application and highlighting from time to time the distinctive factors that guide our choices.

At the end of the operation, we take care to clarify and communicate to the users whether the evaluation is carried out on the overall model or on portions of it and how the results obtained relate to the individual elements investigated. In our applications we define 3 possible validation methods: method "0" provides an indirect verification, based on estimates linked to objects similar in geometrical and functional characteristics to the one analysed; method "1" includes the use of limited assessments (e.g. referring to the coordinates of a few points or on certain distances) directly involving the investigated element; method "2", finally, always comprises the modelled object but is based on the statistical treatment of many measurements, observations or estimates.

The benchmark of our methodology is represented by a portion of a building block, detected with a TLS system and photogrammetric technique in order to obtain a geolocated point cloud through topographic plano-altimetric survey and GNSS data.

Terrestrial laser scanning

The proposed quality assessment for TLS resorts to a homogeneous distribution of 17 checkerboard targets within the scene, detected with the total station and the other previously mentioned techniques. This allows to perform an absolute evaluation, based on the coordinates of specific homologous points. The first step is to identify the sources of uncertainty for this peculiar application:

- primary control network uncertainty (σ_T^2), correlated with the compensation on a sample of direct measurements (with total station, level, GNSS system) to estimate the coordinates of reference network points and detail ones, the latter materialized through checkerboard targets. A rigorous approach should quantify the uncertainty using the standard error ellipsoid (k-value = 1, 19.95% confidence) associated with these points. Sacrificing the criterion of acceptability for measurements, we consider only the major axis of the ellipsoid with k-value = 3 (97.75% confidence) and, from this (a standard deviation σ_T), we define the indicator for this source;

- scan registration uncertainty (σ_R^2), related to the techniques used for alignment [16-18]. For the case study, we use a hybrid on-target and Cloud-to-Cloud solution. For each checkerboard we investigate the distribution of the coordinate values (automatically extracted) in the scans that contains it. These are treated as the observed components of a multidimensional random variable, which we assume to be normal. From the precision of the observations, we derive the one of the estimates and construct the error ellipsoid with k-value = 3, considering its major axis (a standard deviation σ_R) to define the uncertainty indicator, according to the solution seen for the previous source;
- laser uncertainty (σ_L^2), given in its data sheet or obtained from the instrument's calibration check. We follow this second approach. In literature, we can find numerous tests for the accuracy of laser scanners, differentiated between angular and range one [19]. Considering that our evaluation is absolute, i.e., based on coordinates of specific points, while most trials are of relative type, the choice of an appropriate indicator is not easy, bearing in mind also that such an analysis depends on so many factors (reflectance of materials, environmental conditions, etc.) that it is practically impossible to define an unambiguous procedure. For simplicity and availability of reliable data, we use the outputs of a noise test, related to range accuracy. It is a very simple assessment on the deviations that can be performed when a plane surface is scanned and modelled. The resulting discrepancies do not, however, refer to pairs of homologous points and are mainly useful for quantifying the relative accuracy of range measurements. As the geometry of the targets is easily modelled (best-fit plane) and verifiable, we can use the standard deviation of the distances from the best-fit plane to estimate our absolute indicator. Two different surface paints are used: white and black with reflectance of about 90 and 10%, on references positioned at 10 and 25 metres.

As defined, these components are stochastically independent [20, 21]. Assuming these premises and a homogeneous distribution of targets in the scene, we can calculate the overall three-dimensional uncertainty indicator as:

$$\sigma^2 = \sigma_T^2 + \sigma_R^2 + \sigma_L^2 \tag{4}$$

Since 17 checkerboards are employed, the mean and maximum value of all possible variances are selected. The discrepancy between these two values is very useful and is used to check whether there are any outliers to be verified directly on the model. This approach guarantees great flexibility, especially in view of integrated surveys, allowing a possible differentiation of the solutions applied in relation to the single components or elements. The overall indicator is a mean variance (σ_{mean}^2) and, for a quicker interpretation of the uncertainty it represents, we derive the standard deviation (σ_{mean}), which is the size of a length. The approach just presented is an absolute one, but there is nothing to prevent us from following a relative procedure, generally referring to global or local systems.

Photogrammetry
In the case of photogrammetric processes, the assessment of the uncertainty sources cannot be based on the coordinates of the checkerboard targets. In fact, we could think of combining the incertitude associated to the CPs, expressed through the discrepancy between input and output data, with the one related to the support survey to determine the reference coordinates in the object space. However, there is correlation among the two sources of uncertainty, and therefore we cannot apply the propagation law seen in the TLS case. Strictly speaking, only the error associated with CPs should be considered, as the accuracy of the support survey is already counted in the resolution of the Bundle Block Adjustment as input. In any case, basing the whole analysis on a very limited number of points (6 in our application), even if they are homogeneously distributed in the scene, is certainly not a robust approach.

The same argument can be extended to GCPs, with the aggravating circumstance that their coordinates, used to resolve the structure optimization phase, produce a reduction in the error associated with them, unsuitable for evaluations of this kind.

Having explained these concepts, we propose to use a more robust method based on the study of uncertainties concerning the tie points. In the previous chapter, we have clarified how the control of the accuracy of all input data (relative to object space and image space) is of fundamental importance for a rigorous photogrammetric process. In this case, by means of a special Python script we have prepared, we are able to export, after the orientation optimization phase, the covariance matrices associated with the coordinates estimated for the tie points in the object space.

From the matrix, we derive the standard error ellipsoid and the version that corresponds to a probability of containing the theoretical mean value of the coordinates of 97.75% (k =3). Of this last ellipsoid, we consider the major semi-axis and study its distribution for all the tie points, calculating an appropriate tolerance interval. This tool allows us estimating, from a sample, the extremes that contain a certain percentage of a population with a specific level of confidence. The approach therefore seems reasonable, considering that the tie points will constitute only a part of the final photogrammetric cloud. To be fair, the dense image matching phase and its algorithms should also be involved, but this would become too complicated. We will therefore limit ourselves to using the results of the Structure from Motion step here. The following section elaborates on the procedure for determining these ranges.

Modelled accuracy
About the modelled accuracy (Fig. 3. 2), an absolute evaluation against a primary reference system is not an effective answer because it involves a limited number of points. The optimal, and most widely used, solution is to compare the cloud of the

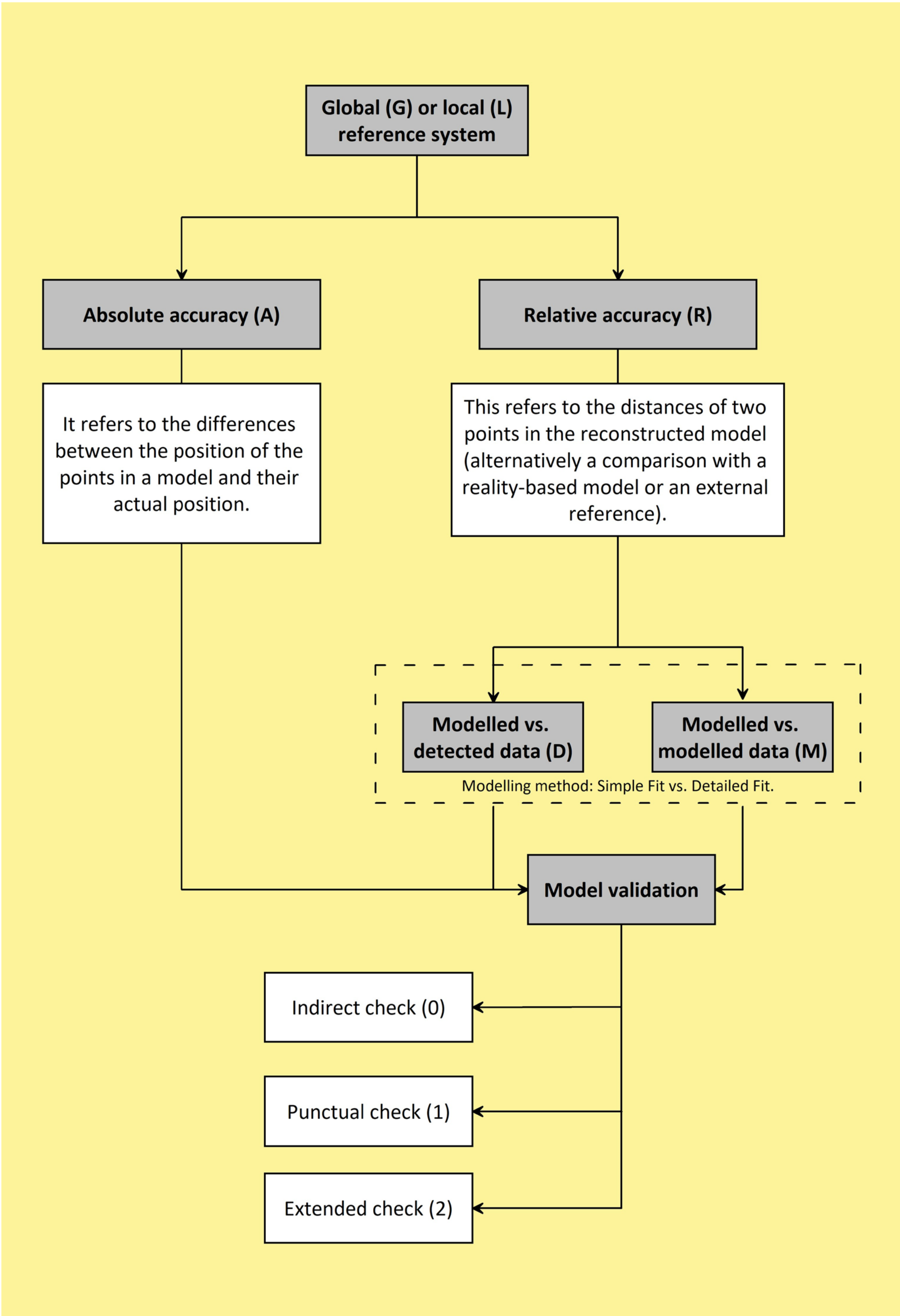

Fig. 3. 2. Framework for tracking the accuracy of parametric modelling (author's elaboration).

survey with the BIM model by analysing the distribution of discrepancies (although the other approaches remain viable, with global or local reference systems).

The main difficulties of this process are twofold: on the one hand, the Euclidean distances used to quantify the differences follow a distribution that is far from the normal one and therefore requires an in-depth study of the statistics employed to describe the phenomenon. On the other hand, a continuous object (the modelled one) is compared with a discrete one (the measured one) and there is no homological correlation between the reciprocal points. In order to overcome these difficulties, we resort to statistical tolerance intervals [22], appropriately constructed by differentiating the procedures according to the shape of the distribution. Once the point cloud of the survey has been fixed as a reference and the algorithm for comparison has been appropriately chosen, the spreading of distances is described. The procedure is divided into 4 phases:

- test for normality [23]. If tenable, we calculate normal tolerance limits;
- search for normalizing transformation (when the distribution is not normal). If an acceptable transformation is found, we calculate normal tolerance limits from transformed data;
- alternative distributions (when transformation approach fails). If a good fit is found, we calculate tolerance limits using the distribution;
- if all approaches fail, we calculate non-parametric tolerance limits.

In any case, it must be ensured that the sample size is adequate for the statistical treatment. All intervals are computed with a confidence coefficient γ of 0.95 and a population proportion P of 0.95. This does not apply to the non-parametric approach, where only one of confidence and proportion can be defined a priori. In the latter case, preventive treatment of the distributions may be necessary to eliminate possible outliers, e.g., by constructing a box-plot diagram.

It is critical to distinguish the difference of a relative measure between detected and represented data (presented above) vs. represented and represented data because, in practical applications, it may be essential to respect tolerance limits according to one or another scenario.

Here again, it will be necessary to clarify and communicate to users how the validation of the analysis has been carried out. The methods proposed for this operation are like those presented for detected accuracy.

3.3 Case study experimentation

Detected accuracy

Terrestrial laser scanning

Regarding the uncertainty linked to the control network, the checkerboard coordinates are to be considered as components of a three-dimensional normal random variable. From their covariance matrix, the error ellipsoids for each target are derived, calculating the length of the semi-axes and their principal direction by orthogonal diagonalization. The probability that the theoretical mean value of the three-dimensional random variable falls within an ellipsoid of k-value = 3 is about 97.75%. To simplify the procedure, the uncertainty indicator (σ_T^2) for each point is defined considering only the maximum semi-axis (σ_T) of the ellipsoid with k = 3, approximating the latter to the sphere with the smallest volume able to contain it. The disadvantage of this approach lies in the loss of the acceptability criterion for the measurements. This is an agreeable simplification given that, because of the way the sphere is constructed, we are 'almost' certain that the theoretical mean value of the aleatory variable falls within it.

Turning to the component dependent on scan registration, the target coordinates are treated as observations of a three-dimensional normal random variable and, from the covariance matrix, a three-dimensional uncertainty indicator is defined (σ_R^2). In essence, a similar path is followed as for the component described above.

For the laser, data from the calibration certificate, such as ranging noise, are used to produce an uncertainty indicator (σ_L^2). As mentioned, this test is of relative type and provides a standard deviation from a best-fit plane for a known flat object located at a defined distance from the instrument. The noise occurs along the measurement direction of the laser. In detail, we use the value obtained with black painted targets (10% reflectance) and placed at 25 m, equal to 0.31 mm. Since in a complex scene it is extremely complicated to control, for each point, the angle of incidence of the light beam, we decided to model this component of uncertainty as a sphere, or better still as a degenerate ellipsoid that has all three axes equal. If the standard deviation allows us to define the standard error ellipsoid (obviously in view of having accepted our simplification), in accordance with the other components derived from a more rigorous process, we have multiplied the length of the standard semi-axis by a scaling factor of 3, obtaining σ_L.

Once the 3 sources are defined, they are expressed in the form of variance and combined according to equation 4 (Table 3. 1).

Photogrammetry

After deriving the error ellipsoid with k-value = 3 and selecting the major semi-axis, we study its distribution to construct an appropriate tolerance interval. Since it is a positive definite quantity, we outline a one-sided interval for a population percentage of 95% and a confidence value of 95%. It should be borne in mind that, in the case of non-parametric tolerance limit calculations, only one of the latter two features can be defined, the other being estimated downstream in the procedure. The analysis conducted for our applications concerns the two projects (close-range and UAV) as a whole, but nothing prevents us from subdividing the cloud into regions (e.g., by individual architectural elements or stratigraphic units) and studying the distributions separately. the most significant analyses are given in Appendix D.

Table 3. 1. Combination of uncertainty sources for TLS survey.

Point ID	σ_T^2 (mm²)	σ_R^2 (mm²)	σ_L^2 (mm²)	σ^2 (mm²)	σ (mm)
1	17.64	1.37	0.86	19.86	4.458
2	12.96	1.51	0.86	15.33	3.915
3	20.25	2.34	0.86	23.45	4.843
4	15.21	3.25	0.86	19.32	4.395
5	20.25	2.24	0.86	23.35	4.832
6	9.00	1.58	0.86	11.44	3.382
7	17,64	2.87	0.86	21.37	4.623
8	10.89	3.04	0.86	14.79	3.846
9	12.96	1.16	0.86	14.98	3.870
10	9,00	1.62	0.86	11.48	3.388
11	10,89	2.54	0.86	14.29	3.780
12	20.25	1.35	0.86	22.46	4.739
13	17.64	2.01	0.86	20.51	4.529
14	5.76	3.21	0.86	9.83	3.14
15	12.96	2.46	0.86	16.28	4.035
16	20.25	1.60	0.86	22.71	4.766
17	7,29	1.18	0.86	9.33	3.06
$\sigma_{mean} = \mathbf{4.09\ mm}$			$\sigma_{MAX} = \mathbf{4.83\ mm}$		

Modelled accuracy

Regarding the modelled accuracy, before performing the comparison, it is good practice to fix the points cloud from the survey as a reference, for the correct evaluation of the normals along which the distances are to be calculated. The algorithm selected to perform this operation is the Multiscale Model to Model Cloud Comparison (M3C2) [24-26], which is more efficient than direct Cloud-to-Cloud (C2C) or Cloud-to-Mesh (C2M) one as it allows considering the uncertainty component related to the TLS station registration [27]. To use it, however, it is necessary to extract a point cloud from the BIM object, taking care that its density is greater or at least equal to that of the cloud derived from the survey. In this specific case, the latter is decimated with a spacing of 0.5 centimetres before being imported into the Revit environment, and the same value is used to extract the points from the BIM object.

Prior to computing the distances employing M3C2, the normals of the reference cloud are calculated using external software (MeshLab 2022.02) [28], selecting a diameter of 5 cm for the neighbour search sphere. This is an appropriate scale for considering all the details that can characterize an architectural façade. Moreover, by performing this operation in advance, we obtain a fixed reference that is not affected by any subsequent iterations of the M3C2 algorithm. The same value of 5 cm is used to define the diameter of the gap calculation cylinder.

The operation delivers oriented distances for which we estimate a two-sided tolerance interval by imposing a population percentage of 95% and a confidence level of 95%. Obviously, only one of the two features can be defined in the case of non-parametric interval calculations. For a better accessibility of the data, the most significant analyses are given in Appendix D.

Accuracy reference labels

Starting from the data collected during the uncertainty component analysis, we produce labels capable of summarizing all relevant information such as the type of reference system, the nature of the assessment (absolute or relative) and above all the degree of accuracy. This is expressed by means of three digits, representing a distance in millimetres. In the case of sub-millimetre values, it is possible to convert some of these numbers into decimals. For two-sided tolerance intervals (modelled accuracy), with oriented gaps, we will select the extreme that has the greatest value in absolute terms. The Table 3. 2 below summarizes the structure of these labels, differentiated by detected and modelled accuracy.

Table 3. 2. Accuracy reference labels.

Detected accuracy				**Modelled accuracy**				
Accuracy	**Reference system**	**Absolute or relative**	**Validation**	**Accuracy**	**Reference system**	**Absolute or relative**	**Detected or modelled**	**Validation**
000	G/L	A/R	0/1/2	000	G/L	A/R	D/M	0/1/2

As an example, we can construct the label for the TLS survey which, based on the design, acquisition and processing of the data will be:

$$4.09GA1 \tag{5}$$

3.4 Remarks and conclusions

Even if we perform a rigorous BIM modelling process, it loses value if information about operational steps and the reliability of the data collected are not implemented in the virtualization itself. The functional aspects of the BIM methodology also include quality assessment, on which the ability to reuse the model depends. Certainly, the best known and most widely used framework is the Level of Development (LOD), which is present in all national and international technical standards with different nuances. In general, it quantifies the grade of depth of the geometric and non-geometric information content of the individual digital objects.

However, there are some critical issues. First, LODs are primarily designed for a new construction process, where the virtualization is enriched as it progresses through the life cycle of the structure. In the case of existing buildings, especially historic ones, this is a problem because the model is built in the management phase and often the data needed to achieve a desired LOD is not easily available. The LOD focuses, then, more on the richness of the information than its quality.

Starting from these assumptions, a procedure has been developed to define the project requirements and evaluate the accuracy of geometric attributes. This is composed of two parts: on the one hand the detected accuracy, referring to the measurements made for the construction of the reality-based model regardless of the method used to acquire them; on the other hand, the modelled accuracy, concerning the detected data processing to produce a source-based virtualization.

The proposed methodology has several strengths: first, it guarantees the traceability of the level of accuracy for the geometric attributes of BIM objects, both in the survey and in the modelling phase. The framework is then compatible with any assigned LOD and with any step of the building life cycle. Future developments will focus on a more rigorous description of the uncertainty components related to the survey and the possibility to define the accuracy levels in a preliminary design phase, according to the tolerances required by the client.

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Final notes

The BIM methodology, together with its associated tools, is still perceived, especially in our country, as an exception to established practice, an eternal novelty with clearly something unfinished. In Europe and worldwide, the branch of BIM, aimed at buildings without cultural connotations, has long remained in the shadows due to a lack of market interest. Only recently has this trend been reversed, particularly in Italy, thanks to tax breaks that have 'boosted' the renovation bonus of '86, such as the Ecobonus and Sismabonus of 2017, the Superbonus 110% of 2020 updated a few months ago by the Budget Law 2022, and others. Market demand has therefore brought attention back to the issue of maintaining the existing building stock, opening a window to the implementation of BIM.

We personally believe that this methodology, by providing an information system on an architectural scale and making it possible to manage semantically enriched three-dimensional models, represents an effective approach to the maintenance of the built heritage if tools and functions suited to its needs are made available. The main objective of this research is therefore to provide a concrete response to the lack of standardized approaches and procedures required for the documentation of the existing fabric, addressing both the technical aspects of model construction, specifically Scan-to-BIM processes, and the functional ones, oriented towards the issues of traceability, reliability, and accuracy of information content.

Starting with the first aspects, it is evident from an analysis of the literature that all too often BIM models are used as alternative forms of describing surveyed data. For this reason, the parameterization of geometric attributes is sacrificed in favour of other modelling methods and representation schemes, which are better suited to the virtualization of complex architectural elements but distort the methodology itself. Continuing, it happens that in reverse engineering processes point clouds, or other survey products, are used as the basis for defining shapes and volumes, with uncontrolled approaches. Reliance is placed on detailed detections that are not always supported by topographical operations, which are indispensable not only for estimating the accuracy of the outputs, but also for defining a common reference system for all products. This violates principles already established by the London Charter of 1945, which reaffirm the importance of accompanying models with information that serves to define their quality. Finally, one forgets that digital techniques, such as photogrammetry and laser scanning, only allow one to detect the ‘skin’ of buildings, to quantify volumes, then requiring further investigation and compositional and material interpretations if one wants to produce a complete parametric virtualization, not only from a geometric but also from an informative point of view.

Our proposal goes against this trend and seeks to provide guidelines for setting up a workflow consistent with the requirements. The survey project represents a cornerstone; it is the cognitive moment in which critical choices are made on techniques and instrumentation that depend not only on the Development Levels of the parametric objects that will constitute the BIM model, but also on the characteristics of the case study. For this reason, we propose surveying solutions that take these and other factors into account, starting from the assumption that detailed detection with digital techniques alone is not sufficient, but must be supported by further acquisitions (total station, GNSS, etc.) to allow geolocation and to build a basic network for data integration operations. Obviously, it is not possible to provide a ‘recipe’ on how to handle these steps, as much depends on the contingencies of the case. However, the stratigraphic complexity of the artefact analysed and its relationship with the surrounding urban context required a careful evaluation of the possible scenarios, producing a range of solutions that, if they do not respond to all the hypothetical criticalities, certainly represent an excellent starting point for a systematization of approaches to digital documentation.

Even the processing phase is not limited to high-level data fusion, which is widespread in the literature, in which the flows of the various techniques are kept separate until the final model is obtained. To maximize the information content of the overall point cloud, data from TLS acquisitions, in the form of individual structured scans, are implemented in the photogrammetric process to support the construction of depth maps in the dense image matching phase. The improvement in the results is of the order of 4-5 mm, which is negligible if the scale of the predetermined representation is 1:50 and which does not justify the possible use of additional techniques. The costs would in fact increase without producing a substantial boost in quality and would burden the private client. The economic issue is particularly relevant in the field of action of Existing BIM and it is necessary to calibrate exactly the resources used. A waste of them would discourage the potential customer from requesting the preparation of a digital product that would then struggle to spread and establish itself as a settled practice. In fact, it should be remembered that, while in the public sector the current legislation requires the complete introduction of BIM by 2025, the same does not apply to the private one, where much is left to the sensitivity of the client and the specifics of the case. This implies the need to optimize procedures to limit their economic impact. This responsibility falls mainly on the technicians working in the sector, the only ones capable of competently guiding the growth and spread of the methodology. Regardless of these premises, the results obtained during data integration are encouraging and could be exploited to develop combined sensor systems capable of providing maximum synergy between the detection techniques employed.

As anticipated, the cognitive framework outlined downstream of the digital survey is certainly not exhaustive and does not guarantee a complete characterization, neither geometric nor informative, of the parametric objects. For this reason, the reality-based models are cross-referenced with technical and administrative documentation in the owner's possession to complete the screening and obtain an exhaustive picture of the assets' situation. This condition, which arose in the case study, is common in the field of heritage management and there is often a total absence of documents, both digital and paper. It therefore becomes impossible (or at any rate extremely time-consuming) to collect the information necessary to achieve the predefined Development Levels, which unfortunately are ill-suited to the reconnaissance processes involving heritage assets. While waiting for a desirable update of the regulations, it is left to the operators to find the technically and economically sustainable solution to meet the standards.

However rigorous the process of constructing a BIM may be, it loses its value if the information on the operational steps and reliability of the collected data is not implemented in the virtualization itself. The functional aspects of the methodology also include quality assessment, on which the possibility of reusing the model depends.

In any BIM process applied to existing buildings, content validation is crucial: the geometric and semantic data must be sufficiently reliable to meet customer-specific requirements and these aspects must be adequately documented. Valid solutions emerge from the literature, but they struggle to establish themselves because they are not well integrated into the tools outlined in the technical standards. For this reason, our proposal for reliability assessment does not introduce any further novelties, but seeks to seek solutions that are already used in parametric modelling or related fields, reformulating them where necessary and lightening the notional load on engineers, who could make use of tools they know and master.

The most interesting aspect for the purposes of an in-depth study of reliability is the verification levels which, together with the other points mentioned in the UNI 11337 standards, delineate the interchange flow. If we want to refer to the construction of the general architectural model for the case study, we are interested in level 1 of formal internal verification that follows the elaboration, and level 2 of substantive verification that follows the sharing and concerns the connection with other models. We intend to take advantage of this framework to insert our proposal, modifying level 1 to no longer just formal but substantial for the individual virtualization and to ascertain the readability, traceability, and consistency of the information.

Having clarified when to carry out the verification, it remains to define how to quantify the reliability of the individual objects that make up the model. In this case, too, a tool is used that is already present in Italian law: the knowledge levels, which measure the degree of learning of a structure, achieved in relation to analysis methods, economic resources, and available time.

All the aspects investigated in this work are fundamental to a methodology such as BIM, which has a strongly interdisciplinary and collaborative character: survey, modelling, chronological analysis, database design, system usability, user-friendliness, etc. are all issues that need to be addressed and are linked to specific disciplines and skills.

The relationships between the existing heritage and technological and methodological innovation are potentially very fruitful. However, for new approaches to be accepted it will take time, also to understand, on a case-by-case basis, what the real improvements are from a technical and economic point of view. The direction is the right one, but many questions are still open and joint efforts are needed to create a general awareness of the importance of the application of BIM methodology in the field of documentation of the existing. Public and private investments, training, appropriate regulations, and shared goals should be undertaken to spread the use of EBIM.

Appendix A: survey tools and techniques

Stonex R1 Plus Total Station

ANGLE MEASUREMENT		**LASER PLUMMET**	
Reading system	Absolute encoder	**Laser type**	635 nm semiconductor laser
Display resolution	1”/5”/10” (0.2/1/2 mgon)	**Accuracy**	1 mm at 1.5 m instrument H
Angle Unit	360°(dms/d) 400 gon/6400 mil	**Laser spot**	±1.5 mm/1.5 m
Accuracy[1]	2”	**LEVEL VIAL SENSITIVITY**	
TELESCOPE		**Plate level**	30 (“2 mm)
Magnification/Length	30x/156 mm	**Circular level**	8 (‘/2 mm)
Field of view	1° 30’	**ENVIRONMENTAL CONDITIONS**	
Minimum focus	1.0 m	**Operating Temperature**	-20° C to +50° C
Reticle	9 brightness levels adjustable	**Storage Temperature**	-40° C to +10° C
Objective aperture	φ 45 mm	**Waterproof/ Dustproof**	IP66
AUTOMATIC COMPENSATOR		**PHYSICAL SPECIFICATION**	
System	liquid detection dual axis compensator	**Dimensions**	175 mm x 178 mm x 340 mm

Compensation range/Accuracy	±3'/1"	**Weight (including battery and tribrach)**	5.1 kg
DISTANCE MEASUREMENT RANGE		**BATTERY**	
Reflectorless	2.0 ~ 600[2] m	**Voltage/Capacity**	7.4 V/3400 mAh Li-ion battery
With Prism	2.0 ~ 3000[3] 2000[4] 1500[5] Class 1 up to 5000 m Class 3	**Operating period with continuous angle measurement**	36 hours
With reflective sheet (60 x 60 mm)	2.0 ~ 800 m	**Operating period with measurement every 30 seconds**	26 hours (>1.000 measurement at 20° C)
MEASUREMENT ACCURACY		**OTHER SPECIFICATIONS**	
Reflectorless	±(3 + 2 x 10^{-6} D) mm	**Display**	Two sides, LCD, 96 x 160 dots
Prism	±(2 + 2 x 10^{-6} D) mm	**Memory**	120000 points, support SD card 16 Gb
Reflective sheet (60mm x 60mm)	±(3 + 2 x 10^{-6} D) mm	**Interface**	RS-232C/mini-USB/SD card
MEASUREMENT TIME		**Charger**	110/220 V, Charging time: about 4 hours
Measuring time (Tracking/Fast/Fine)	0.4 s/0.6 s/1.0 s		
Distance Unit	m/ft/US ft		

[1] Standard deviation based on ISO 17123-3.
[2] Visibility about 40 km, back light less than 5000 lx, no haze, no direct sunlight.
[3] Visibility about 40 km, sunny, no heat shimmer.
[4] Visibility about 20 km, moderate sunlight, slight heat shimmer.
[5] Visibility about 10 km, light haze. severe heat shimmer.

Stonex STAL 1132 Optical Autolevel

ACCURACY		**COMPENSATOR**	
Standard deviation per km (double run levelling	1.5 mm	**Compensator**	V Hanging wire. magnetic damping
TELESCOPE		**Compensator range**	±15'
Image	Erect	**Setting accuracy**	±0.3"
Resolving power	4.2"	**Thread**	5/8"
Magnification	32x	**PHYSICAL SPECIFICATIONS**	
Objective aperture	36 mm	**Net Weight**	1.2 kg (with box and accessories 2.25 kg)

Field of view	1° 20’	**Waterproof/ Dustproof**	IP54
Minimum focusing distance	0.4 m		
Stadia multiplication constant	100		
Stadia addition constant	0		
Circular level accuracy	8’/2 mm		
Hor. circle graduation	1° (DEG model)/1 Gon (GON model)		

GeoMax Zenith25 PRO GNSS Receiver

GENERAL		**INTERFACES**	
Q-Lock™ technology	Lowest noise and multipath mitigation	**Keyboard**	On/off and function keys
Satellites (Max. number tracked simultaneously)	60	**LED status and mode indicators**	Position, battery, Bluetooth®, RTK receive, RTK transmit, storage card; Rover, base, static
Channels	120	**Data recording**	8 GB removable microSD card
GPS tracking	L1, L2, L2C	**GSM / TCP / IP**	Removable SIM card
GLONASS tracking	L1, L2	**POWER SUPPLY**	
BeiDou tracking	B1*	**External power/ Internal battery**	10.5 V to 28 V/ Removable 2.6 Ah; 7.4 V
Galileo tracking	E1*	**Operating time (static/rover)**	9 h/6 h
Positioning rate	20Hz*, 5Hz	**PHYSICAL SPECIFICATIONS**	
SBAS	EGNOS, WAAS, MSAS, GAGAN	**Dimensions/Weight**	Height 95 mm, ø 198 mm/1.2 kg incl. battery & UHF radio
ACCURACY**		**Operating temperature**	– 40°C to + 65°C
Static H/V (mm + ppm)	3 + 0.5/5 + 0.5	**Protection class**	IP68 - withstands dust and immersion in water
Static long H/V (mm + ppm)	3 + 0.1/3.5 + 0.4	**Humidity**	100%, condensing
Kinematic H/V (mm + ppm)	8 + 1/15 + 1	**Vibration**	Mechanical stress resistant according ISO 9022-36-05
COMMUNICATION		**Shock**	Withstands 2m topple over onto hard surface

GSM/GPRS module	Quad-Band GSM & Penta-Band; UMTS 800/850/900/1900/2100 MHz; internal antenna	*Optional ** Measurement accuracy and reliability are dependent on various factors including satellite, geometry, obstructions, observation time, ionospheric conditions, multipath, etc. Figures quoted assume normal to favourable conditions.
UHF radio module	1000 mW transceiver; 406 - 480 MHz; Optional	
Bluetooth®	Device class II	
Communication port	USB, serial, and power	

FARO Focus^{3D} X 330 Laser Scanner

RANGING UNIT			
Unambiguity interval		By 122 till 488 Kpts/s at 614 m; by 976 Kpts/s at 307 m	
Range Focus3D X 330		0,6 m to 330 m indoor or outdoor with normal incidence to a 90% reflective surface	
Measurement speed (pts/s)		122,000/244,000/488,000/976,000	
Ranging error[1]		±2 mm	
Ranging noise[2]		**@10 m**	**@25 m**
	@ 90% refl.	0.3 mm	0.3 mm
	@ 10% refl.	0.4 mm	0.5 mm
COLOUR UNIT			
Resolution		Up to 70-megapixel colour	
Dynamic colour feature		Automatic adaption of brightness	
Parallax		Co-axial design	
DEFLECTION UNIT			
Field of view (vertical/horizontal)		300°/360°	
Step size (vertical/horizontal)		0,009° (40,960 3D-Pixel on 360°)/0,009° (40,960 3D-Pixel on 360°)	
Max. vertical scan speed		5,820 rpm or 97 Hz	
LASER (OPTICAL TRANSMITTER)			
Laser class		Laser class 1	
Wavelength		1550 nm	
Beam divergence		Typical 0,19 mrad (0,011°) (1/e, halfangle)	
Beam diameter at exit		Typical 2,25mm (1/e)	
DATA HANDLING AND CONTROL			
Data storage		SD, SDHC™, SDXC™; 32GB card included	
Scanner control		Via touchscreen display and WLAN	
New WLAN access		Remote control, scan visualisation and download are possible on mobile devices with Flash®	
MULTI-SENSOR			
Dual axis compensator		Levels each scan: Accuracy 0,015°; Range ± 5°	

Height sensor	Via an electronic barometer the height relative to a fixed point can be detected and added to a scan
Compass[4]	The electronic compass gives the scan an orientation. A calibration feature is included
GPS	Integrated GPS receiver

[1] Ranging error is defined as a systematic measurement error at around 10m and 25m, one sigma.
[2] Ranging noise is defined as a standard deviation of values about the best-fit plane for measurement speed of 122,000 points/sec.
[3] A noise-compression algorithm may be activated to average points in sets of 4 or 16, thereby compressing raw data noise by a factor of 2 or 4. Subject to change without prior notice.
[4] Ferromagnetic objects can disturb the earth magnetic field and lead to inaccurate measurements.

CALIBRATION RESULTS

Ranging

Target	**Distance (m)**	**Uncertainty, k=1 (mm)**	**Scanner (m)**	**Deviation (mm)**	**Specifications**
EU14	9.4562	0.496	9.4559	0.3	2.0
ZK21	23.5592	0.496	23.5585	0.7	2.0

Ranging Noise

Reflectance	**Distance (m)**	**Uncertainty, k=1 (mm)**	**Scanner (mm)**	**Specification**
90%	**10**	0.067	0.20	0.3
	25	0.067	0.20	0.3
10%	**10**	0.067	0.21	0.4
	25	0.067	0.31	0.5

FUJIFILM X-T100 Mirrorless Camera

Model Name		FUJIFILM X-T100
Number of effective pixels		24.2 million pixels
Image sensor		23.5 mm x 15.7 mm (APS-C) CMOS with primary colour filter
Sensor Cleaning system		Ultra-Sonic Vibration
Storage media		SD Card (- 2GB)/SDHC Card (- 32GB)/SDXC Card (- 256GB) UHS-I*[1]
File format	**Still image**	JPEG (Exif Ver 2.3)*[2]/RAW (RAF format)/ RAW+JPEG (Design rule for Camera File system compliant/DPOF-compatible)
	Movie	Movie File Format: MOV Movie Video Compression: H.264 Audio: Linear PCM Stereo
Number of recorded pixels		L: (3:2) 6000 x 4000/(16:9) 6000 x 3376/(1:1) 4000 × 4000 M: (3:2) 4240 x 2832/(16:9) 4240 x 2384/(1:1) 2832 × 2832 S: (3:2) 3008 x 2000/(16:9) 3008 x 1688/(1:1) 2000 × 2000
		Motion Panorama 180°: Vertical: 2160 x 9600/Horizontal: 9600 x 1440

		120°: Vertical: 2160 x 6400/Horizontal: 6400 x 1440
Lens mount		FUJIFILM X mount
Sensitivity	**Standard Output**	AUTO1/AUTO2/AUTO3 (up to ISO6400)/ ISO200 to 12800 (1/3 step)
	Extended output	ISO100/25600/51200
Exposure control		TTL 256-zone metering, Multi / Spot / Average
Exposure mode		P (Program AE)/ A (Aperture Priority AE)/ S (Shutter Speed Priority AE)/ M (Manual Exposure)
Exposure compensation		-5.0 EV/+5.0 EV, 1/3 EV step (Movie recording: - 2.0 EV/+ 2.0 EV)
Face detection		Yes
Eye detection		Yes
Shutter type		Focal Plane Shutter
Shutter speed (with mechanical shutter)	**Mechanical Shutter**	4 s to 1/4000 s (P mode), 30 s to 1/4000 s (All modes), Bulb mode (up to 60 min), TIME: 30 s to 1/4000 s
	Electronic Shutter*[3]	4 s to 1/32000 s (P mode), 30 s to 1/32000 s (All modes), Bulb mode (1 s fixed), TIME: 30 s to 1/32000 s
	Mechanical + Electronic Shutter	4 s to 1/32000 s (P mode), 30 s to 1/32000 s (All modes), Bulb mode (up to 60 min), TIME: 30 s to 1/32000 s
	Synchronized shutter speed for flash	1/180 s or slower
Continuous shooting		Approx. 6.0 fps (JPEG: max. approx. 26 frames) Approx. 3.0 fps (JPEG: max. up to card full) * Use a card with UHS Speed Class 1 * Speed of continuous shooting depends on shooting environment and shooting frames
Auto bracketing		AE Bracketing (2/3/5/7 frames) ±1/3 EV-±3 EV, 1/3 EV step Film Simulation Bracketing (Any 3 types of film simulation selectable) Dynamic Range Bracketing (100% · 200% · 400%) ISO sensitivity Bracketing (±1/3 EV, ±2/3 EV, ±1 EV) White Balance Bracketing (±1, ±2, ±3)
Focus	**Mode**	Single AF/Continuous AF/MF/AF+MF
	Type	Intelligent Hybrid AF: TTL contrast AF/TTL phase detection AF, AF assist illuminator available
	AF frame selection	Single point AF: 7 x 13 (Changeable size of AF frame among 5 types), Zone AF: 3 x 3/5 x 5/7 x 7 from 91 areas on 7 x 13 grid, Wide/Tracking AF: (up to 18 area) * AF-S: Wide * AF-C: Tracking
White balance		Automatic Scene recognition/Custom 1 - 3/ Colour temperature selection (2500K-10000K)/ Pre-set: Fine, Shade, Fluorescent light (Daylight), Fluorescent light (Warm White), Fluorescent light (Cool White), Incandescent light, Underwater

Self-timer		2 s/10 s/Smile/ Buddy (LV.1 - LV.3)/Group (1 - 4 subjects)/Face Auto Shutter
Flash		Manual pop-up flash (Super Intelligent Flash) Guide number: Approx. 5 (ISO100 · m)/ Approx. 7 (ISO200 · m)
Flash modes	**Red-eye removal OFF**	Auto/Forced Flash/Suppressed Flash/Slow Synchro/Rear-curtain Synchro/Commander
	Red-eye removal ON	Red-eye Reduction Auto/Red-eye Reduction & Forced Flash/Suppressed Flash/ Red-eye Reduction & Slow Synchro/Red-eye Reduction & Rear-curtain Synchro/Commander * Red-eye removal is active when Face Detection is set to ON
Hot shoe		Yes (dedicated TTL Flash compatible)
Viewfinder		0.39-in., Approx. 2,360K-dot OLED colour viewfinder, Coverage of viewing area vs. capturing area: Approx. 100% Eye point: Approx. 17.5mm (from the rear end of the camera's eyepiece), Dioptre adjustment: -4m/+2m-1 (dpt) Magnification: 0.62x with 50 mm lens (35mm format equivalent) at infinity and dioptre set to -1m-1 Diagonal angle of view: Approx. 30° (Horizontal angle of view: Approx. 25°) Built-in eye sensor
LCD monitor		3.0-inch, aspect ratio 3:2, approx. 1,040K-dot 3-way Tilt-type, TFT colour LCD monitor
Movie recording		4K 3840 x 2160 15P, Continuous recording: up to approx. 30 min. Full HD 1920 x 1080 59.94p/50p/24p/23.98p, Continuous recording: up to approx. 30 min. HD 1280 x 720 59.94p/50p/24p/23.98p, Continuous recording: up to approx. 30 min. High Speed Movie 1280x720 1.6x/2x/3.3x/4x, Continuous recording: up to approx. 7 min. * For 4K movie recording, use a card with UHS Speed Class 3 or higher * Although movie recording will continue without interruption when the file size reaches 4 GB, subsequent footage will be recorded to a separate file which must be viewed separately
Mode dial		Advanced SR AUTO/P/S/A/M/Night/Sports/Landscape/ Portrait Enhancer/SP (Scene Position)/Adv./Panorama
Film Simulation mode		11 types (PROVIA/STANDARD, Velvia/VIVID, ASTIA/SOFT, CLASSIC CHROME, PRO Neg Hi, PRO Neg. Std, MONOCHROME, MONOCHROME+Ye FILTER, MONOCHROME+R FILTER, MONOCHROME+G FILTER, SEPIA)
Dynamic range setting		AUTO, 100%, 200%, 400% ISO restriction (DR100%: No limit, DR200%: ISO400 or more, DR400%: ISO800 or more)
Advanced filter		Toy camera, Miniature, Pop colour, High-key, Low-key, Dynamic tone, Fish-eye, Soft focus, Cross screen, Partial colour (Red/Orange/Yellow/Green/Blue/Purple), Fog remove, HDR Art

Touch screen	**Shooting Mode**	Touch Shooting, AF, Focus Area, OFF Touch Function, EVF Touch Screen Area Settings (ALL, RIGHT, LEFT, UPPER RIGHT, UPPER LEFT, LOWER RIGHT, LOWER LEFT, OFF)
	Playback Mode	Swipe, Zoom, Pinch-in/Pinch-out, Double-tap, Drag
Other photography functions		4K Burst, 4K Multi Focus, HDR, Electronic level, Advanced SR AUTO, Eye detection AF, Face Detection, Interval timer shooting, Auto Red-eye Removal, Motion panorama, Colour space, Setting (Colour, Sharpness, D-range, Gradation), Film Simulation, Advanced Filter, Framing guideline, Frame No. memory, Histogram display, Preview depth of focus, Pre-AF, Focus check, Focus Peak Highlight, Multiple exposure, Release priority / Focus priority selection, Fn button setting, ISO AUTO control, Interlock spot AE & Focus area, Edit/Save quick menu, Preview exp./WB in manual mode, Shutter Type, Touch screen setting
Playback functions		RAW conversion, Image rotate, Auto image rotate, Face Detection, Red-eye reduction, Photobook assist, Erase selected frames, Multi-frame playback (with micro thumbnail), Slide show, Protect, Crop, Resize, Panorama, Favorites
Wireless transmitter	**Standard**	IEEE 802.11b/g/n (standard wireless protocol)
	Access mode	Infrastructure
	Encryption	WEP/WPA/WPA 2 mixed mode
Bluetooth®	**Standards**	Bluetooth Ver. 4.1 (Bluetooth low energy)
	Operating frequency	2402 - 2480MHz
Wireless functions [Centre frequency]		Geotagging setup, Image transfer (Individual image/Selected multiple images), View & Obtain Images, PC Autosave, instax Printer Print, Pairing registration, Delete pairing registration, Bluetooth ON/OFF setting, Auto image transfer
Other functions		Exif Print, 35 Languages, Date/Time, Time difference, Sound & Flash OFF, Quick start Mode, High Performance, Preview exp. in Manual mode, LCD Brightness, LCD Colour, Preview Pic. Effect, DISP. Custom Setting, EVF Brightness, EVF Colour
Terminal	**Video output**	-
	Digital interface	USB 2.0 High-Speed/micro-USB terminal
	HDMI output	HDMI Micro connector (Type D)
	Microphone/remote release connector	⌀ 2.5 mm 3 - pole mini jack
Power supply	**Battery life for still images*[4]**	Approx. 430frams (Normal Mode) When XF35mmF1.4 R is set.
	Actual battery life of movie capture*[4]	* Face detection is set to OFF 4K: approx. 90 min., FULL HD: approx. 100 min.

	Continuance battery life of movie capture*4	* Face detection is set to OFF 4K: approx. 150 min., FULL HD: approx. 170 min.
Dimensions		121.0 (W) mm x 83.0 (H) mm x 47.4 (D) mm/4.8 in.(W) x 3.3 in. (H) x 1.9 in. (D) (Minimum depth: 33.4 mm/1.3 in.)
Weight		Approx. 448 g/15.8 oz. (including battery and memory card) Approx. 399 g/14.1 oz. (excluding accessories, battery, and memory card)
Operating Temperature		0 to +40° C / +32 to +104° F
Operating Humidity		10% to 80% (no condensation)
Starting up period		Approx. 0.4 s, when High Performance mode set to ON Approx. 0.8 s, when High Performance mode set to OFF * Fujifilm research
Accessories included		Li-ion battery NP-W126S, AC power adapter, Plug Adapter, USB cable, Shoulder strap, Body cap, Owner's manual, Detachable Grip
*[1] Please check the Fujifilm website for memory card compatibility. *[2] Exif 2.3 is a file format for digital cameras that contains various shooting information to optimise image printing. *[3] The electronic shutter may not be suitable for fast-moving objects. The flash cannot be used. *[4] Approximate number of frames/operating time with a fully charged battery according to CIPA standard.		

DJI Mini 2 Aircraft

AIRCRAFT	
Dimensions	Folded: 138×81×58 mm (L×W×H) Unfolded: 159×203×56 mm (L×W×H) Unfolded (with propellers): 245×289×56 mm (L×W×H)
Diagonal Distance	213 mm
Max Ascent Speed	5 m/s (S Mode) 3 m/s (N Mode) 2 m/s (C Mode)
Max Descent Speed	3.5 m/s (S Mode) 3 m/s (N Mode) 1.5 m/s (C Mode)
Max Speed (near sea level, no wind)	16 m/s (S Mode) 10 m/s (N Mode) 6 m/s (C Mode)
Max Service Ceiling Above Sea Level	4000 m
Max Flight Time	31 mins (measured while flying at 4.7 m/s in windless conditions)
Max Wind Speed Resistance	8.5-10.5 m/s (Scale 5)
Max Tilt Angle	40° (S Mode) 25° (N Mode)* 25° (C Mode)* * Up to 40° under strong winds

Max Angular Velocity (by default)*	130°/s (S Mode) 60°/s (N Mode) 30°/s (C Mode) * Can be adjusted to 250°/s with the DJI Fly app
Operating Temperature	0° to +40° C (+32° to +104° F)
Operating Frequency[2]	2.400 - 2.4835 GHz, 5.725 - 5.850 GHz
Transmitter Power (EIRP)	2.400 - 2.4835 GHz FCC ≤ 26 dBm CE ≤ 20 dBm SRRC ≤ 20 dBm 5.725-5.850 GHz FCC ≤ 26 dBm CE ≤ 14 dBm SRRC ≤ 26 dBm
Global Navigation Satellite System (GNSS)	GPS+GLONASS+GALILEO
Hovering Accuracy Range	Vertical: ±0.1 m (with Vision Positioning), ±0.5 m (with GPS Positioning) Horizontal: ±0.3 m (with Vision Positioning), ±1.5 m (with GPS Positioning)
GIMBAL	
Mechanical Range	Tilt: -110° to 35° Roll: -35° to 35° Pan: -20° to 20°
Controllable Range	Tilt: -90° to 0° (default setting) -90° to +20° (extended)
Stabilization	3-axis (tilt, roll, pan)
Max Control Speed (tilt)	100°/s
Angular Vibration Range	±0.01°
SENSING SYSTEM	
Downward	Hovering Range: 0.5 - 10 m
Operating Environment	Non-reflective, discernible surfaces Diffuse reflectivity (> 20%, such as cement pavement) Adequate lighting (lux > 15, Normal exposure environment of indoor fluorescent lamp)
CAMERA	
Sensor	1/2.3" CMOS Effective Pixels: 12 million pixels
Lens	FOV: 83° 35 mm format equivalent: 24 mm Aperture: f/2.8 Focus range: 1 m to ∞
ISO	Video: 100 - 3200 (Auto) 100 - 3200 (Manual) Photos:

	100 - 3200 (Auto) 100 - 3200 (Manual)
Shutter Speed	Electronic Shutter: 4-1/8000 s
Max Image Size	4:3: 4000 × 3000 16:9: 4000 × 2250
Still Photography Modes	Single Shot Interval: JPEG: 2/3/5/7/10/15/20/30/60 s JPEG+RAW: 5/7/10/15/20/30/60 s Auto Exposure Bracketing (AEB): 3 bracketed frames at 2/3 EV Bias Panorama: Sphere, 180°, and Wide-angle
Video Resolution	4K: 3840 × 2160 @ 24/25/30fps 2.7K: 2720 × 1530 @ 24/25/30/48/50/60fps FHD: 1920 × 1080 @ 24/25/30/48/50/60fps
Max Video Bitrate	100 Mbps
Zoom Range	4K: 2x 2.7K: 3x FHD: 4x
QuickShot Modes	Dronie, Helix, Rocket, Circle, Boomerang
Supported File Formats	FAT32 (≤ 32 GB) exFAT (> 32 GB)
Photo Formats	JPEG/DNG (RAW)
Video Formats	MP4 (H.264/MPEG-4 AVC)
REMOTE CONTROLLER & VIDEO TRANSMISSION	
Operating Frequency	2.400 - 2.4835 GHz, 5.725 - 5.850 GHz
Max Transmission Distance (unob-structed, free of interference)[3]	10 km (FCC) 6 km (CE) 6 km (SRRC) 6 km (MIC)
Signal Transmission Ranges (FCC)[4]	Strong Interference (urban landscape, limited line of sight, many competing signals): Approx. 3 km Medium Interference (suburban landscape, open line of sight, some competing signals): Approx. 6 km Low Interference (open landscape abundant line of sight, few competing signals): Approx. 10 km
Operating Temperature	-10° to +40° C (+14° to +104° F)
Transmission Power (EIRP)	2.400 - 2.4835 GHz FCC ≤ 26 dBm CE ≤ 20 dBm SRRC ≤ 20 dBm MIC ≤ 20 dBm 5.725-5.850 GHz

	FCC ≤ 26 dBm CE ≤ 14 dBm SRRC ≤ 26 dBm
Battery Capacity	5200 mAh
Voltage	1200 mA 3.6 V (Android) 700 mA 3.6 V (iOS)
Supported Mobile Device Size	180 × 86 × 10 mm (Height × Width × Thickness)
Supported USB Port Types	Lightning/Micro USB (Type-B)/USB-C
Video Transmission System	When used with different aircraft hardware configurations, both remote controllers will automatically select the corresponding firmware version for updating and support the following transmission technologies enabled by the hardware performance of the linked aircraft models: a. DJI Mini 2/ DJI Mavic Air 2: O2 b. DJI Air 2S: O3 c. DJI Mavic 3: O3+
Live View Quality	Remote Controller: 720p/30fps
Max Bitrate	8 Mbps
Latency (depending on environmental conditions and mobile device)	About 200 ms
CHARGER	
Input	100 - 240 V, 50/60 Hz, 0.5 A
Output	12V 1.5 A 9V 2A 5V 3A
Rated Power	18 W
INTELLIGENT FLIGHT BATTERY	
Battery Capacity	2250 mAh
Voltage	7.7 V
Charging Voltage Limit	8.8 V
Battery Type	LiPo 2S
Energy	17.32 Wh
Weight	86.2 g
Charging Temperature	+5° to +40°C (+41° to +104°F)
Max Charging Power	29 W
APP	
Name	DJI Fly
Required Operating System	iOS v10.0 or later/Android v6.0 or later

SUPPORTED SD CARDS	
Supported SD Cards	UHS-I Speed Class 3 or above is required. A list of recommended microSD cards can be found below
Recommended microSD Cards	16 GB: SanDisk Extreme 32 GB: Samsung Pro Endurance, Samsung Evo Plus, SanDisk Industrial, SanDisk Extreme V30 A1, SanDisk Extreme V30 A2, SanDisk Extreme Pro V30 A1, SanDisk Extreme Pro V30 A2, Lexar 633x, Lexar 667x 64 GB: Samsung Pro Endurance, Samsung Evo Plus, SanDisk Extreme V30 A2, Lexar 633x, Lexar 667x, Lexar 1000x, Lexar High Endurance, Toshiba EXCERIA M303 V30 A1, Netac Pro V30 A1 128 GB: Samsung Evo Plus, SanDisk Extreme V30 A2, SanDisk Extreme Plus V30 A1, SanDisk Extreme Plus V30 A2, Lexar 633x, Lexar 667x, Lexar 1000x, Lexar High Endurance, Toshiba EXCERIA M303 V30 A1, Netac Pro V30 A1 256 GB: SanDisk Extreme V30 A2
FOOTNOTES	
Footnotes	[1] The standard weight of the aircraft (including battery, propellers, and a microSD card) is 242 grams. Actual product weight may vary. Registration is not required in some countries and regions. Check local rules and regulations before use. These specifications have been determined through tests conducted with the latest firmware. Firmware updates can enhance performance, so updating to the latest firmware is highly recommended. [2] Due to local policy and regulation restrictions, the 5.8 GHz frequency band is currently banned in certain countries, including but not limited to Japan, Russia, Israel, Ukraine, and Kazakhstan. Please use the 2.4 GHz frequency band when operating in these locations. Always check local rules and regulations before use, as they may change over time. [3] Maximum flight range specification is a proxy for radio link strength and resilience, not aircraft battery capability. It only refers to the maximum, one-way flight distance. Data was measured in an open environment without interference. Please pay attention to the return prompt on the DJI Fly app during actual flight. Refer to the following applicable standard in different countries and regions: FCC: United States, Australia, Canada, Hong Kong, Taiwan, Chile, Colombia, Puerto Rico, and other regions; SRRC: Mainland China; CE: UK, Russia, France, Germany, Portugal, Spain, Switzerland, Macau, New Zealand, UAE, and other regions; MIC: Japan. [4] Data is tested under different standards in open areas free of interference. It only refers to the maximum, one-way flight distance without considering Return to Home. Please pay attention to RTH prompts in the DJI Fly app during actual flight.

Camera models in Agisoft Metashape

The software supports several parametric lens distortion models. A specific model which approximates best a real distortion field must be selected before processing. All models assume a central projection camera. Non-linear distortions are modelled using Brown's distortion model.

A camera model specifies the transformation from point coordinates in the local camera coordinate system to the pixel coordinates in the image frame.

The local camera coordinate system has an origin at the projection centre. The Z axis points towards the viewing direction, X axis points to the right, Y axis points down. The image coordinate system has origin in the middle of the top-left pixel (with coordinates (0.5, 0.5)). The X axis in the image coordinate system points to the right, Y axis points down. Image coordinates are measured in pixels.

Equations used to project a point in the local camera coordinate system to the image plane are provided below. The following definitions are used in the equations:

- **(X, Y, Z)**, point coordinates in the local camera coordinate system;
- **(u, v)**, projected point coordinates in the image coordinate system (in pixels);
- **f**, focal length (in pixels);
- $\mathbf{c_x, c_y}$, principal point offset (in pixels);
- $\mathbf{K_1, K_2, K_3, K_4}$, radial distortion coefficients (dimensionless);
- $\mathbf{P_1, P_2}$, tangential distortion coefficients (dimensionless);
- $\mathbf{B_1, B_2}$, affinity and non-orthogonality (skew) coefficients (in pixels);
- **w, h**, image width and height (in pixels).

Frame Cameras

- $x = X/Z$;
- $y = Y/Z$;
- $r = \mathrm{sqrt}(x^2 + y^2)$;
- $x' = x(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_1(r^2+2x^2) + 2P_2xy)$;
- $y' = y(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_2(r^2+2y^2) + 2P_1xy)$;
- $u = w \cdot 0.5 + c_x + x'f + x'B_1 + y'B_2$;
- $v = h \cdot 0.5 + c_y + y'f$.

Appendix B: information management plan (*pGI*)

Foreword

Project identification

The structure under investigation falls within the municipality of *Siano*, located in the north-western area of the province of *Salerno*. It is a built lot at the crossroads between *Via Marconi*, in the historic core of the town, and *Vicolo Capuano*. The features of the complex formal structure, depending on its relationship with the site, the urban space, and the lot itself, allow it to be traced back to the block type. The building is morphologically and structurally compact, with three free sides and a small open space, off-centre and connected to a minor private road, which provides access to the upper floors.

From a plano-altimetrical point of view, the block is the result of successive transformations and mergers since the end of the 19th century, presenting a particular composition with mezzanines and heterogeneity in terms of structural typology. We can identify three levels above ground, completed by a fourth interposed between the first and second floors, and two basements, accessible from the above-mentioned decentralized open space.

There is also heterogeneity from a structural point of view. Vertical elements are mainly constructed of bonded natural stone masonry. More specifically, it is yellow Neapolitan tuff, a rather incoherent rock of pyroclastic nature, formed by the compaction and cementing of volcanic materials of explosive origin. This masonry is present both in the form of rough stones with mortar, in relation to the 19th-century core, and in the form of hewed elements with mortar, for the extensions carried out during the 20th century. The building renovation of the early 21st century introduced volumes with a reinforced concrete frame structure cast in situ. The horizontal elements, on the other hand, consist of mixed cast-in-place concrete and brick slabs, except for a single floor made of steel and brick stringers. Lastly, the cover is made up of a pitched roof, also in brick and concrete.

From an urbanistic point of view, the lot falls, for the built-up part, in the *ZTO A2*, with buildings and complexes that do not present characteristics of relevance but constitute the prevalence of the consolidated fabric. The open areas, on the other hand, fall within *ZTO A3* of the pertinences.

The owners are interested in learning more about his property for several reasons. Firstly, the building has undergone many transformations over the years, which have not always been fully documented. It is therefore necessary to verify that the integration of the various interventions has been properly taken care of and that the structural elements are not affected by problems. The same applies to the energy aspects. An appropriate Asset Information Model can support a simulation of the power behaviour of the building in order to highlight possible criticalities. More specifically, it is a general architectural virtualization produced for the execution stage, i.e., for the management and maintenance phases indicated in UNI 11337-1:2017.

Table B. 1. Summary project identification.

Employers	di Filippo Rocco and di Filippo Maria
Project name	HOME
Type of work	General Architectural AIM
Summary description	The building block to be documented is divided into two real estate units belonging to two different owners
Geographical location	Vicolo Capuano n° 4/ Via Marconi n° 29, 84088 Siano (SA), Italy
Construction phase	Operation stage/management and maintenance phases

Introduction

The benefits deriving from the use of an Asset Information Model are many and involve all the actors in the supply chain, both on the client side and on the service provider one. Among the most significant advantages we can report:

- documentation of the asset through a shared and coordinated design environment, minimizing the exchange of information between those involved in the various disciplines, areas, and systems, in order to limit the data redundancy and optimize processing times for future projects;
- integrated design, based on the participation of all the players in the supply chain; the individual specialist teams will operate together on production

from a single multidisciplinary asset model, developed to ensure the transparency of the process and the sharing of work progress and able to show criticalities and interferences;
- optimization of control over the entire building life cycle, with reference to strictly management activities (estimation of material quantities, price analysis, paperwork administration);
- delivery to the contractor of a complete documentation thanks to the use of the model, which can be interrogated through free visualization software and can be used as a basis for the phases of intervention on the artefact (Development stage) and for maintenance and management (Operation stage).

This document represents the description of the methods and processes used to enjoy the benefits that Building Information Modelling makes possible when applied in the correct manner. The *pGI* is a dynamic and evolving document; each subsequent version will be released with appropriate revision numbering and publication date; some chapters or paragraphs will be developed in later issues as information becomes available.

Acronyms and glossary

Table B. 2. Acronyms in the document and their descriptions.

Acronym	**Description**
ACDat	Common Data Environment (Italian)
ACDoc	Paper or physical document sharing environment
AEC	Architectural, Engineering and Construction or Annual Equivalent Cost
AEC/FM	Architecture, Engineering, Construction and Facilities Management AIA
AIM	Asset Information Model/Modelling
AIR	Asset Information Requirements
AM	Asset Management
API	Application Programming Interface
BEP	BIM Execution Plan
BIM	Building Information Model / Modelling / Management
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
CAPEX	Capital Expenditure

CDE	Common Data Environment
CI	Exchange Information Requirements (Italian)
COBie	Construction-Operations Building information exchange
EIR	Exchange Information Requirements (formerly called Employer's Information Requiremens)
FM	Facilities Management
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAI	International Alliance for Interoperability (now known as BuildingSMART)
ICT	Information and Communications Technology
ID	Identification
IDM	Information Delivery Manual
IDP	Information Delivery Plan
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization IaaS 'Infrastructure as a Service'
IT	IT Information Technology
LIDAR	Light detection and ranging
LOD	Level of Development
LOG	Level of Development - Geometric Attributes
LOI	Level of Development - Information Attributes
LOIN	Level of Information Need
MEP	Mechanical, electrical, and plumbing
MIDP	Master Information Delivery Plan
MVD	Model View Definition
oGI	BIM Execution Plan - pre contract (Italian)
OIB	Organization Information HandBook
OIR	Organizational Information Requirements
OPEX	Operational Expenditure
pGI	BIM Execution Plan - post contract (Italian)
PIM	Project Information Model

PIP	Project Implementation Plan
PIR	Project Information Requirements
RGB	Red Green Blue
TIDP	Task Information Delivery Plan

Normative References

The document is drawn up in accordance with UNI 11337, which are the reference for any further details and definitions. It also incorporates all the superordinate updates contained in UNI EN ISO 19650 and in UNI EN 17412. The Table B. 3 provides more information.

Table B. 3. Main normative references.

UNI 11337-1:2017	Building and civil engineering works - Digital management of the informative processes - Part 1: Models, documents and informative objects for products and processes
UNI/TR 11337-2:2021	Building and civil engineering works - Digital management of the informative processes - Part 2: Management of information flows and decision-making processes by appointing party
UNI/TS 11337-3:2015	Building and civil engineering works - Codification criteria for construction products and works, activities and resources - Part 3: Models of collecting, organizing, and recording the technical information for construction products
UNI 11337-4:2017	Building and civil engineering works - Digital management of the informative processes - Part 4: Evolution and development of information within models, documents, and objects
UNI 11337-5:2017	Building and civil engineering works - Digital management of the informative processes - Part 5: Informative flows in the digital processes
UNI/TR 11337-6:2017	Building and civil engineering works - Digital management of the informative processes - Part 6: Guidance to redaction the informative specific information
UNI 11337-7:2018	Building and civil engineering works - Digital management of the informative processes - Part 7: Knowledge, skill, and competence requirements of building information modelling profiles
UNI/PdR 78:2020	Requirements for conformity assessment to UNI 11337-7:2018 “Construction and civil engineering works - Digital management of information processes in buildings - Part 7: Requirements for knowledge, skills and competence of the professional figures involved in information management and modelling”
UNI EN ISO 19650-1:2019	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 1: Concepts and principles

UNI EN ISO 19650-2:2019	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 2: Delivery phase of the assets
UNI EN ISO 19650-3:2021	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 3: Operational phase of the assets
UNI EN ISO 19650-5:2020	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 5: Security-minded approach to information management
UNI EN 17412-1:2021	Building Information Modelling - Level of Information Need - Part 1: Concepts and principles
BS 1192:2007+A2:2016	Collaborative production of architectural, engineering and construction information - Code of practice

Technical Section

Hardware infrastructure

Table B. 4. Hardware infrastructure related to the different activities.

Field	**Objective**	**Specification**
Survey, Architectural design and Model checking	Data Processing	Intel Core i7-4790K 8M Cache, up to 4.40 GHz
	Temporary data storage	Samsung DDR3 1600 MHz 4 x 8 GB Dual channel
	Data transmission	ASUSTeK G30AK
	Data storage	Kingstone SSD 512 GB
	Data backup storage	Toshiba HDD 2 TB
	Graphic Processing	NVIDIA GeForce GTX 980 4 GB memory
	Data display	LG QHD monitor
Other	Data Processing	Intel Core i5-8250U 6M Cache, up to 3.40 GHz
	Temporary data storage	Crucial DDR4 2400 MHz 4 + 8 GB Single channel
	Data transmission	Acer mainboard
	Data storage	Kingstone SSD 128 GB
	Data backup storage	Lexar microSD 256 GB
	Graphic Processing	NVIDIA GeForce MX150 2 GB memory
	Data display	LG FHD panel

Software infrastructure

Table B. 5. Software infrastructure related to the different disciplines.

Field	Discipline	Software	Compatibility with open formats
Survey	Topography	Leica Infinity 3.6	TXT, CSV, others
	Laser scanning	Faro SCENE 2019.0.0.1457	DXF, E57, IGES, POD, PTS, PTX, VRML, XYZ
	Photogrammetry	Agisoft Metashape Professional (version 1.8.2 build 13956)	See user manual for export formats for 2D and 3D products
Architectural design	BIM modelling	Autodesk Revit 2022	IFC, PDF
	Geometric analysis	CloudCompare 2.11.3	ASCII, PLY, OBJ, VTK, STL, E57, LAS, FBX, SHP, PTX, others
	Geometric analysis	MeshLab 2020.12	PLY, STL, OBJ, VRML, X3D
	Statistical treatment	Statgraphics Centuri-on 19.1.2	CSV
Model checking	Clash detection	Autodesk Revit 2022	IFC, PDF

Data supply and exchange

Table B. 6. Data exchange formats.

Objective	Format	
	Open	**Owner**
BIM modelling	IFC	RVT
2D graphical representation	DXF, PDF	DWG
Model review and conflict analysis	IFC	RVT
Computing activities	CSV	XLSX
Maintenance and manage-ment attributes	PDF, CSV	XLSX
Text documents	PDF, TXT	DOCX
Presentations	PDF	PPTX
Others	Miscellaneous	Miscellaneous

Common coordinate system and reference specifications

The topographic survey allows the identification of a common reference system for all the source-based models, according to the client's indications. In this case, the network consists of a closed polygon with 4 framing points, the latter being subject to geometric levelling operations for a rigorous plano-altimetric detection. For measurements of azimuthal angles, performed with a total station, we make use of Bessel's rule.

The topographic survey is supplemented with GNSS positioning techniques, using a single receiver on the vertices of the network in order to perform its compensation and insert it into a national reference system. For an integrated use of the different sources, it is necessary to take care of the geolocation, expressed in a Geodetic Reference System recognized by the regulations in force; in the case of Europe this system is the ETRS89, which in Italy translates into the realization ETRF2000 (epoch 2008.0). The use of the latter, based on the GRS80 ellipsoid, is in fact an obligation for the Public Administration, sanctioned by *Decreto del Presidente del Consiglio dei Ministri del 10 novembre 2011* (administrative document), as well as indicated in the European directive INSPIRE (Technical Guidelines Annex I - D2.8.I.1). For the municipality of Siano, therefore, the cartographic reference system required by law will be UTM33/ETRF2000 identified by code EPSG:7792.

GNSS acquisitions are performed in static mode (sampling rate 1") for two vertices of the network, whose coordinates will be considered known. For the reminder, approximate coordinates are acquired using nRTK measurements. In both cases, an elevation angle of 15° is used. The data are processed in single-base mode and, for the static application, precise ephemerides are downloaded 28 days after the date of the survey for the satellite trajectories.

The framing points of the reference network are materialized by means of centring nails, fitted with washers, driven into the road pavement while, for the detail ones, artificial checkerboard targets are used, appropriately distributed on the faces of the block for a total of 17. Monographs are drawn up for the reference points, accompanied by sketches and photographs.

Object entry specification

Table B. 7. Relative reference system for objects.

Object	Specification
Finishing layers of ceiling and suspended ceilings	All the finishing layers placed between the ceiling and the suspended ceiling are associated with the level/environment below them
Horizontal elements	Apart from roofs and finishing layers, all the horizontal elements are associated with the reference level on which they lie
Walls	All walls are modelled as discrete elements with constraints to the various defined reference levels

Management Section

Information goals and uses of the models and outputs

Table B. 8. Model goals with respect to the process phases.

Phase	Objective	Model	Objective
Maintenance and management	Ensure that the work performs correctly and is maintained/improved until the end of its technical, functional, and economic life cycle	ARCH GEN	Contain objects for the architectural building and construction elements (e.g., interior partitions, exterior closures, fixtures, interior doors, etc.)

<u>Model uses with respect to the defined goals</u>: the general architectural virtualization of the asset that we will deliver to the client can be used for the current operation and for the ordinary and extraordinary maintenance of the building or its parts.

Table B. 9. Digital graphical output.

Output	Note	Origin
Plants	For each floor above ground	From model
	For each underground floor	
	Roof level	
Sections	Significant	From model
Views	All	From models
Knots	Significant for technology	Graphical output
Documentary outputs	All	From model

Levels of Development of the objects and information sheets

The specification of Levels of Development for virtual objects is a central issue. Based on UNI 11337-4:2017 and referring to an existing building surveyed and then modelled (Execution stage), we might be led to attribute the product to a *LOD G*, where the digital objects express the updated virtualization of the state of an entity at a defined time, containing the trace of management, maintenance, repairs, and replacements carried out throughout the life cycle of the work. While this direct correspondence may apply to the geometric aspect (we will see that the problem is more complex than it seems), the same does not apply to the information content, which is dependent on the cognitive process. The standard levels are conceived with reference to a forward engineering methodology, where data increase as one moves from the idea to the concrete object.

A solution to the problem could be to decouple the two aspects, already identified by UNI standards as Geometric attributes (*LOG*) and Information attributes (*LOI*), which however cannot be treated separately today. A big problem concerns the geometry. Just think of the detailed knowledge of the stratigraphy that must be achieved to reach a *LOD G*. This is certainly a simple but revealing example. Returning to the case study, based on the above considerations, it is not possible to acquire deep knowledge for all information and geometric aspects. The same architectural survey, carried out with photogrammetric and laser scanning techniques, is limited to an exhaustive documentation of the 'skin' of the building, without however providing information regarding the 'non-visible' elements, such as the stratigraphy of the walls. It is therefore evident that the LOD system needs to be rethought in relation to the type of building, as it is extremely difficult and above all costly for a private individual to implement the techniques and technologies necessary to collect the missing data.

For this specific case, models and outputs deriving from the survey are integrated with documents of various kinds (projects, deeds, etc.) in paper format and historical images rigorously archived by the owners, in order to outline a cognitive framework compatible with the objectives and uses of the model. It is therefore possible to achieve a *LOD G* for all virtualized architectural elements, although it is not possible to validate all geometric and non-geometric attributes in the field. This is a major problem, but one that could not be solved by solutions economically compatible with the client's availability.

Fortunately, UNI EN ISO 19650 and UNI EN 17412, with the introduction of the LOIN concept, allow us to go beyond the static approach of LODs and to calibrate the information contents with respect to a conscious and mature demand, providing in fact mixed LODs for virtualized elements.

Information content security and protection policies

Table B. 10. Normative references for security.

Information security management systems	
ISO/IEC 27000:2018	Information technology - Security techniques - Information security management systems - Overview and vocabulary
ISO/IEC 27001:2013	Information technology - Security techniques - Information security management systems - Requirements
ISO/IEC 27002:2013	Information technology - Security techniques - Code of practice for information security controls
ISO/IEC 27005:2018	Information technology - Security techniques - Information security risk management
ISO/IEC 27007:2020	Information security, cybersecurity, and privacy protection - Guidelines for information security management systems auditing
ISO/IEC TS 27008:2019	Information technology - Security techniques - Guidelines for the assessment of information security controls

Privacy	
ISO/IEC 29100:2011/AMD 1:2018	Information technology - Security techniques - Privacy framework
Professional profiles	
UNI 11506:2021	Unregulated professional activities - Professions in the ICT domain - Requirements for the assessment and certification of knowledge, skills, autonomy, and responsibility for ICT professional profiles based on the e-CF framework
UNI 11621-2:2021	Unregulated professional activities - ICT professional role profiles - Part 2: "Second generation" role professional profiles
UNI 11621-4:2017	Unregulated professional activities - ICT professional profiles - Part 4: Information security professional profiles
Techniques and technologies	
ISO/IEC 9798-1:2010	Information technology - Security techniques - Entity authentication - Part 1: General
ISO/IEC 18033-1:2021	Information security - Encryption algorithms - Part 1: General
ISO/IEC 27039:2015	Information technology - Security techniques - Selection, deployment and operations of intrusion detection and prevention systems (IDPS)
ISO/IEC 27040:2015	Information technology - Security techniques - Storage security
ISO/IEC 29115:2013	Information technology - Security techniques - Entity authentication assurance framework

Data, information, and information content sharing methods

Characteristics of the common infrastructure: in accordance with UNI 11337 parts 5 and 6 and in order to ensure the digital management of the building documentation process, we set up a shared data collection environment (*ACDat*). On the platform we will upload:

- models (mainly in proprietary format) and outputs;
- proceeding paperwork;
- everything necessary for open collaboration.

The CDE, hosted on a web space provided by us, has a structure that follows the guidelines established by BS 1192:2007+A2:2016 and inherited by UNI 11337. The interchange flow is managed by a system of encoding for information content to define a particular status and by approval cycles that allow the change of condition and thus the evolution of data for a given use, up to final archiving. The first level of folders identifies 4 areas that correspond to the same number of stages:

- **work in progress**, the state in which the information content is under development; the models or documents are in a draft condition (in process) and have no character of completeness or validity. In practice, we are in the phase where design teams work individually, without any official interdisciplinary coordination;

- **shared**, the area or state where information content that has undergone an approval process converges. In this condition, the data can be exchanged between the various project teams and with the client;
- **published**, the area or state in which information content that has undergone an approval action is usable for a given purpose (tender, costs, executive design, etc.). It is the place where the valid and official data reside at a precise moment in the information process;
- **archive**, the area/status where all outdated material converges, i.e., which has ceased to be proper for the purposes for which it was produced, and the final versions of each model and document at the end of the information cycle.

The structure proposed for this application is closer to an English CDE than to an *ACDat*, presenting itself more as a shared container, a digital archive, without delving into the automated and computerized relational aspect.

Each stage has its own structure (second level) as follows:

- **models**, be they source and reality-based, calculation or simulation virtualizations;
- **outputs**, whether graphic, documentary or multimedia;
- **information sheets**, to define relationships between models and outputs in a structured way;
- **supporting documents**, not directly related to the interchange flow, but useful for sharing data.

The third and final level makes a breakdown by relevant discipline. Non-digital information documents (such as, for example, paper originals of previous reports, any non-digital reproductions of projects or extractions - views - of models, such as printed plans, elevations, and sections) are instead collected in another dedicated space (physical) intended for the storage and organized sharing of paperwork, i.e., the *ACDoc* with a structure like that of the *ACDat*. As suggested by UNI 11337, in order to guarantee a complete electronic information process, non-digital documents are previously digitized (with 600 dpi resolution) and consequently collected in the *ACDat*.

<u>File naming</u>: the Italian UNI 11337 standards deal with the subject in an oversimplified way. In part 6 they suggest a possible coding of files based on a few data. As we consider this solution to be inflexible and not applicable to a wide range of cases, we have instead followed the scheme proposed by BS 1192:2007+A2:2016. Below is the structure of the fields, i.e., the spaces reserved for metadata, which will constitute the ID of the documents in a Common Data Environment. Each one is associated with a representative encoding:

- **field 1 (Project, 2 to 6 digits)** must uniquely define the project by means of a code which, for example, identifies the assignment contract or the project lot, etc.;

- **field 2 (Originator, 3 to 6 digits)** identifies the team that created the file;
- **field 3 (Volume or System, 2 digits)** deals with the physical subdivision of the project which breaks it down into volumetric units, assigned to the individual role (described in field 6). In the case of no parcelling (i.e., only one volume considered) the field shall be occupied by the code ZZ;
- **field 4 (Levels and Locations, 2 digits)** concerns the possible division into levels or zones. In the absence of this, the code ZZ is used;
- **field 5 (Type, 2 digits)** identifies a particular content and BS 1192 standards provide tables containing differentiated coding for models/outputs and documents;
- **field 6 (Role, 1 digit)** concerns the role of the author of the file within the team;
- **field 7 (Classification, optional)** indicates whether any categorization system is used during the development of the file;
- **field 8 (Number, 4 digit)** concerns the unique identification of the file with sequential enumeration;
- **field 9 (Suitability, optional)** indicates the degree of adequacy of the information content. It may be completed according to its own specific coding or use the standard one proposed in BS 1192. For this application we will use a combination of the verification, coordination and approval levels introduced by UNI 11337;
- **field 10 (Revision, optional)** indicates the status of the file.

For the sake of brevity, we do not list all the tables needed to fill in these fields, which are easily retrievable by consulting the standards BS 1192:2007+A2:2016.

Model, object and/or output verification and validation procedure

<u>Definition of the verification process organization</u>: The UNI11337 standards, in parts 4 and 5, provide useful guidance on the coordination, publication, verification and approval of information content in relation to the chosen Common Data Environment. The most interesting aspect for the purposes of an in-depth examination of reliability is represented by the verification levels which, together with the other three points mentioned above, outlines the interchange flow.

If we want to refer to the construction of the general architectural model for this application, we are interested in level 1 of formal internal verification which follows the elaboration, and level 2 of substantial verification which follows the sharing and concerns the link with other models. We intend to take advantage of this framework to include our proposal, modifying level 1 which is no longer just formal but substantial for the individual virtualization and is aimed at ascertaining the readability, traceability, and consistency of the information.

<u>Definition of the validation procedures</u>: having clarified when to carry out the verification, it remains to define how to quantify reliability of the individual ob-

jects that make up the model (and consequently of the outputs and documents derived from them). Once again, we use a tool that is already present in the Italian regulations: the levels of knowledge, which quantify the degree of learning about a facility, achieved in relation to structural analysis methods, economic resources, and time available. They are described by the Technical Standards for Construction (*NTC 2018*) and the relevant circular, but have been present in state legislation for many years. Our proposal introduces three main innovations compared to what is already laid down in the regulation:

- the presence of a level 0 representing the absence of information;
- the provision of a single classification system that does not depend on construction techniques;
- the separation of levels for the properties and characteristics investigated for individual objects.

Moreover, we replace the term knowledge with reliability in order to avoid ambiguity with Italian acronyms, that coincide with those of the levels of coordination in the interchange flow, a sign that homogeneity is still lacking in the national regulations of the AEC sector. The informative contents dealt with are referred to the single objects: historiographic, geometric, structural, and material. For the first ones, as anticipated, an in-depth study is required because it is not sufficient to clarify how the building is detected, but it is also necessary to consider what the uncertainties on the measurements are.

Information clash or inconsistency analysis and resolution process
Project clashes: within the framework of coordination level 1, we carry out clash detection between all the objects constituting the general architectural model (hard and soft), also checking the resulting outputs.

Project inconsistencies: within coordination level 1, we perform code-checking with respect to Italian national legislation and that of the Campania Region

Definition of the clash and inconsistency resolution methods: during the verification and validation operations, the critical points found will be directly resolved, producing a summary report and generating an appropriate revision of the file.

Methods for archiving and final delivery of information models, objects and/or outputs
At the end of the activities, the client will receive a complete backup of the CDE, stored on an appropriately sized HDD.

Appendix C: archival documentation

Agenzia Entrate

Direzione Provinciale di Salerno
Ufficio Provinciale - Territorio
Servizi Catastali

Data: 23/12/2019 - Ora: 10.52.36 Segue
Visura n.: T66541 Pag: 1

Visura per soggetto
limitata ad un comune
Situazione degli atti informatizzati al 23/12/2019

Dati della richiesta	**DI FILIPPO ROCCO**
	Terreni e Fabbricati siti nel comune di SIANO (Codice: I720) Provincia di SALERNO
Soggetto individuato	**DI FILIPPO ROCCO nato a SIANO il 01/09/1951 C.F.: DFLRCC51P01I720H**

1. Unità Immobiliari site nel Comune di SIANO(Codice I720) - Catasto dei Fabbricati

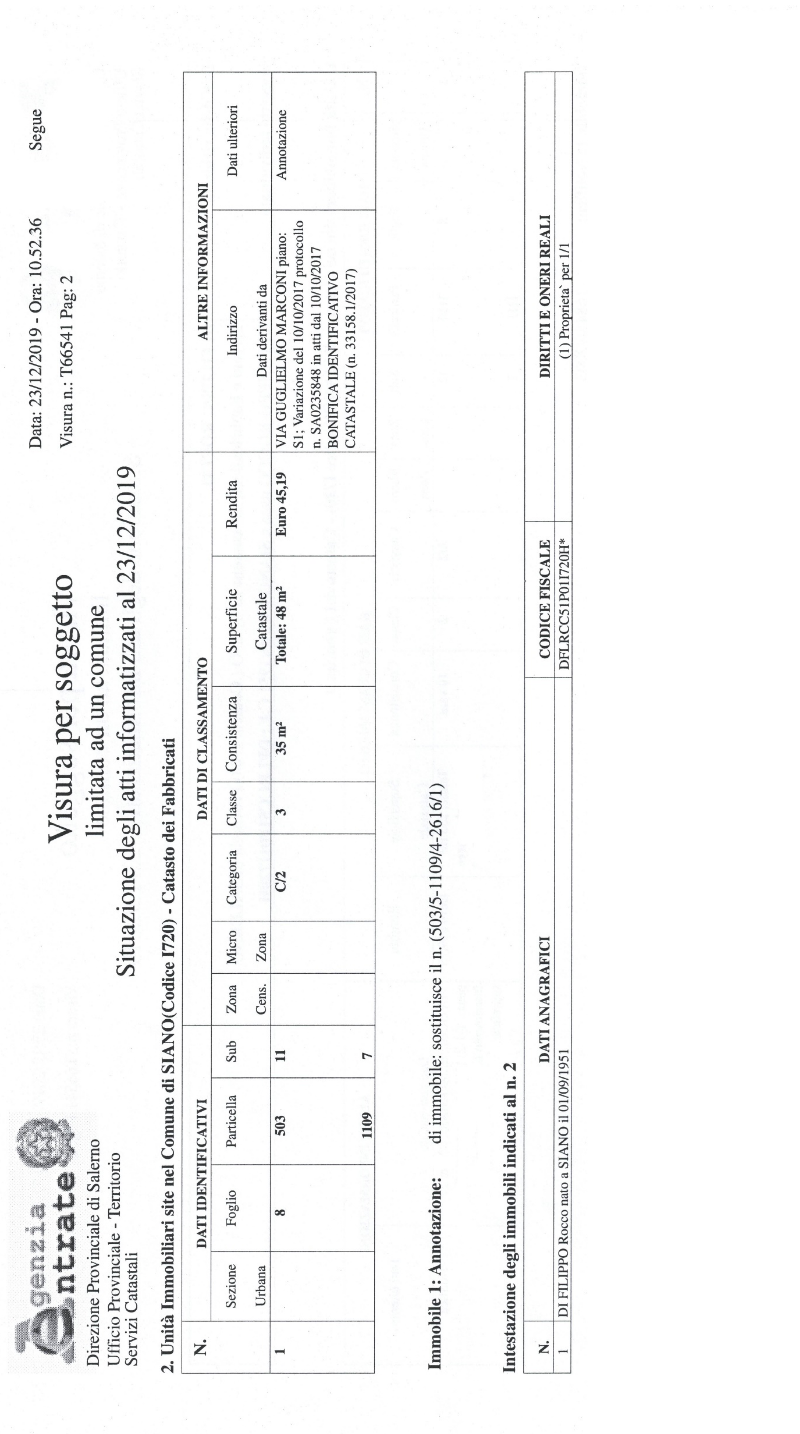
N.	DATI IDENTIFICATIVI				DATI DI CLASSAMENTO							ALTRE INFORMAZIONI	
	Sezione Urbana	Foglio	Particella	Sub	Zona Cens.	Micro Zona	Categoria	Classe	Consistenza	Superficie Catastale	Rendita	Indirizzo / Dati derivanti da	Dati ulteriori
1		8	1110	12			A/2	2	10 vani	Totale: 253 m² Totale escluse aree scoperte**: 240 m²	Euro 619,75	VIA GUGLIELMO MARCONI n. 27 piano: T-1-2; Variazione del 09/11/2015 - Inserimento in visura dei dati di superficie.	Notifica
			1111	7									

Immobile 1: Notifica: 168456/2003

Intestazione degli immobili indicati al n. 1

N.	DATI ANAGRAFICI	CODICE FISCALE	DIRITTI E ONERI REALI
1	DI FILIPPO Rocco nato a SIANO il 01/09/1951	DFLRCC51P01I720H*	(1) Proprieta` per 1/1
DATI DERIVANTI DA	ISTRUMENTO (ATTO PUBBLICO) del 19/12/2002 protocollo n. 305418 Voltura in atti dal 02/07/2003 Repertorio n.: 9008 Rogante: C. PETRAGLIA Sede: BATTIPAGLIA Registrazione: UR Sede: EBOLI Volume: 999999 n: 9999999 del 07/01/2003 DONAZIONE (n. 41406.1/2003)		

Fig. C. 1. Title search from building registry of the real estate unit owned by di Filippo Rocco.



Agenzia Entrate

Direzione Provinciale di Salerno
Ufficio Provinciale - Territorio
Servizi Catastali

Data: 23/12/2019 - Ora: 10.52.36 Segue

Visura n.: T66541 Pag: 2

Visura per soggetto

limitata ad un comune

Situazione degli atti informatizzati al 23/12/2019

2. Unità Immobiliari site nel Comune di SIANO(Codice I720) - Catasto dei Fabbricati

N.	DATI IDENTIFICATIVI				DATI DI CLASSAMENTO							ALTRE INFORMAZIONI	
	Sezione Urbana	Foglio	Particella	Sub	Zona Cens.	Micro Zona	Categoria	Classe	Consistenza	Superficie Catastale	Rendita	Indirizzo / Dati derivanti da	Dati ulteriori
1		**8**	**503**	**11**			**C/2**	**3**	**35 m²**	**Totale: 48 m²**	**Euro 45,19**	VIA GUGLIELMO MARCONI piano: S1; Variazione del 10/10/2017 protocollo n. SA0235848 in atti dal 10/10/2017 BONIFICA IDENTIFICATIVO CATASTALE (n. 33158.1/2017)	Annotazione
			1109	**7**									

Immobile 1: Annotazione: di immobile: sostituisce il n. (503/5-1109/4-2616/1)

Intestazione degli immobili indicati al n. 2

N.	DATI ANAGRAFICI	CODICE FISCALE	DIRITTI E ONERI REALI
1	DI FILIPPO Rocco nato a SIANO il 01/09/1951	DFLRCC51P01I720H*	(1) Proprieta` per 1/1

Fig. C. 2. Title search from building registry of the cellar owned by di Filippo Rocco.

Agenzia Entrate
Direzione Provinciale di Salerno
Ufficio Provinciale - Territorio
Servizi Catastali

Data: 23/12/2019 - Ora: 10.58.00 Segue
Visura n.: T69150 Pag: 1

Visura per soggetto
limitata ad un comune
Situazione degli atti informatizzati al 23/12/2019

Dati della richiesta	**DI FILIPPO MARIA**
	Terreni e Fabbricati siti nel comune di SIANO (Codice: I720) Provincia di SALERNO
Soggetto individuato	**DI FILIPPO MARIA nata a SIANO il 09/11/1946 C.F.: DFLMRA46S49I720M**

1. Unità Immobiliari site nel Comune di SIANO(Codice I720) - Catasto dei Fabbricati

N.	DATI IDENTIFICATIVI				DATI DI CLASSAMENTO							ALTRE INFORMAZIONI	
	Sezione Urbana	Foglio	Particella	Sub	Zona Cens.	Micro Zona	Categoria	Classe	Consistenza	Superficie Catastale	Rendita	Indirizzo Dati derivanti da	Dati ulteriori
1		8	1110 1111	7 2			A/2	2	5,5 vani		Euro 340,86 L. 660.000	VIA GUGLIELMO MARCONI piano: T; COSTITUZIONE del 19/01/1995 in atti dal 17/12/1999 (n. 11.1/1995)	

Intestazione degli immobili indicati al n. 1

N.	DATI ANAGRAFICI	CODICE FISCALE	DIRITTI E ONERI REALI
1	DI FILIPPO Maria nata a SIANO il 09/11/1946	DFLMRA46S49I720M*	(1) Proprieta` per 1/1
DATI DERIVANTI DA	DENUNZIA (NEI PASSAGGI PER CAUSA DI MORTE) del 08/12/2001 protocollo n. 55506 in atti dal 13/02/2002 Registrazione: Sede: RIUNIONE DI USUFRUTTO (n. 50336.2/2002)		

Fig. C. 3. Title search from building registry of the real estate unit owned by di Filippo Maria.

Agenzia Entrate

Direzione Provinciale di Salerno
Ufficio Provinciale - Territorio
Servizi Catastali

Visura per soggetto
limitata ad un comune
Situazione degli atti informatizzati al 23/12/2019

Data: 23/12/2019 - Ora: 10.58.00 Segue
Visura n.: T69150 Pag: 2

2. Unità Immobiliari site nel Comune di SIANO(Codice I720) - Catasto dei Fabbricati

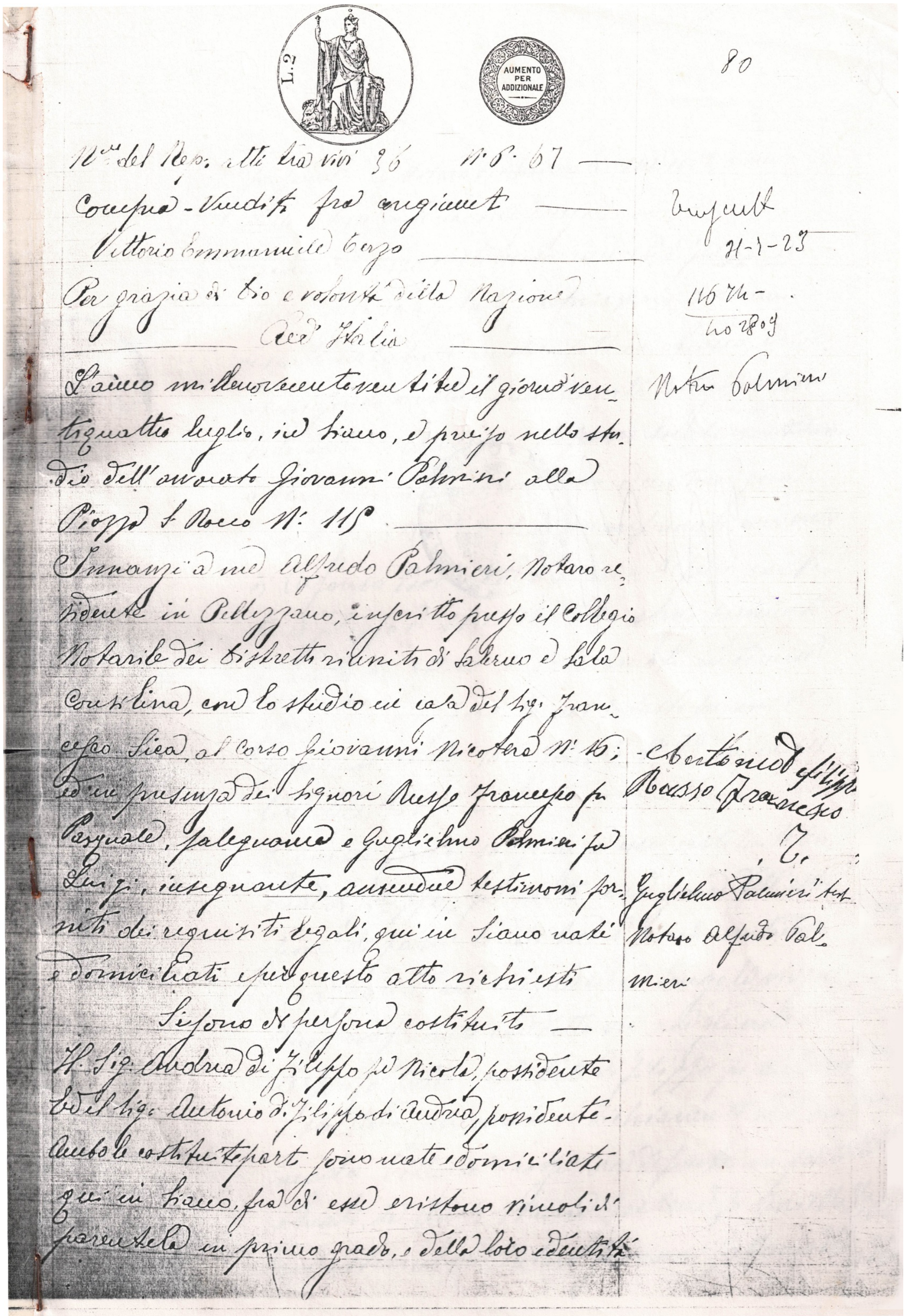
N.	DATI IDENTIFICATIVI				DATI DI CLASSAMENTO							ALTRE INFORMAZIONI	
	Sezione Urbana	Foglio	Particella	Sub	Zona Cens.	Micro Zona	Categoria	Classe	Consistenza	Superficie Catastale	Rendita	Indirizzo Dati derivanti da	Dati ulteriori
1		8	503 1109	10 6			C/2	3	38 m²	Totale: 55 m²	Euro 49,06	VIA GUGLIELMO MARCONI piano: S1; VARIAZIONE del 06/12/2019 protocollo n. SA0220714 in atti dal 06/12/2019 RETTIFICA ANNOTAZIONE (n. 55543.1/2019)	Annotazione

Immobile 1: Annotazione: di immobile: sostituisce il n. (503/6-1109/5-2616/2) - istanza n.216153/19-sostituisce il n. (503/6-1109/5-2616/2) - istanza n.216153/19-sostituisce il n. (503/6-1105/6-2616/2)

Intestazione degli immobili indicati al n. 2

N.	DATI ANAGRAFICI	CODICE FISCALE	DIRITTI E ONERI REALI
1	DI FILIPPO Maria nata a SIANO il 09/11/1946	DFLMRA46S49I720M*	(1) Proprieta` per 1/1

Fig. C. 4. Title search from building registry of the cellar owned by di Filippo Maria.


80

N.° del Rep. atti tra vivi 36 N.° 67

Compra - Vendita fra congiunti

Vittorio Emmanuele Terzo

Per grazia di Dio e volontà della Nazione

Re d'Italia

L'anno millenovecentoventitrè il giorno ventiquattro luglio, in Siano, e presso nello studio dell'avvocato Giovanni Palmieri alla Piazza S. Rocco N. 115

Innanzi a me Alfredo Palmieri, Notaro residente in Pellezzano, iscritto presso il Collegio Notarile dei Distretti riuniti di Salerno e della Costalina, con lo studio in casa del Sig. Francesco Sica, al Corso Giovanni Nicotera N. 16; ed in presenza dei Signori Russo Francesco fu Pasquale, falegname e Guglielmo Palmieri fu Luigi, insegnante, ambedue testimoni forniti dei requisiti legali, qui in Siano nati e domiciliati per questo atto richiesti

Si sono di persona costituiti

Il Sig. Andrea di Filippo fu Nicola, possidente ed il Sig. Antonio di Filippo di Andrea, possidente. Ambo le costituite parti sono nate e domiciliate qui in Siano, fra di essi esistono vincoli di parentela in primo grado, e della loro identità

Registrato 21-1-23

Notar Palmieri

Antonio di Filippo

Russo Francesco

Guglielmo Palmieri test.

Notaro Alfredo Palmieri

Fig. C. 5. Extract 1 of the deed of sale between family members which allows an approximate dating of the original core of the building block.

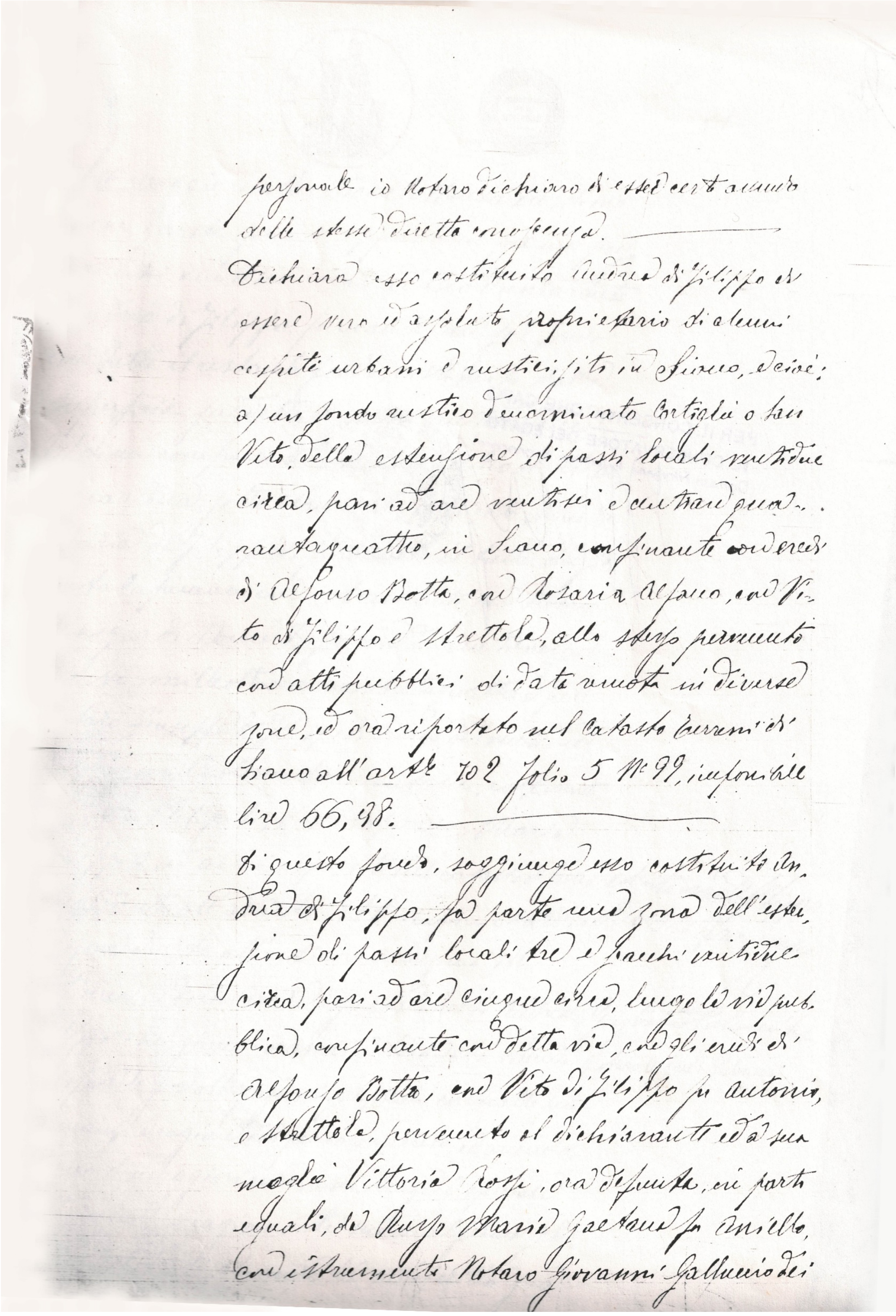
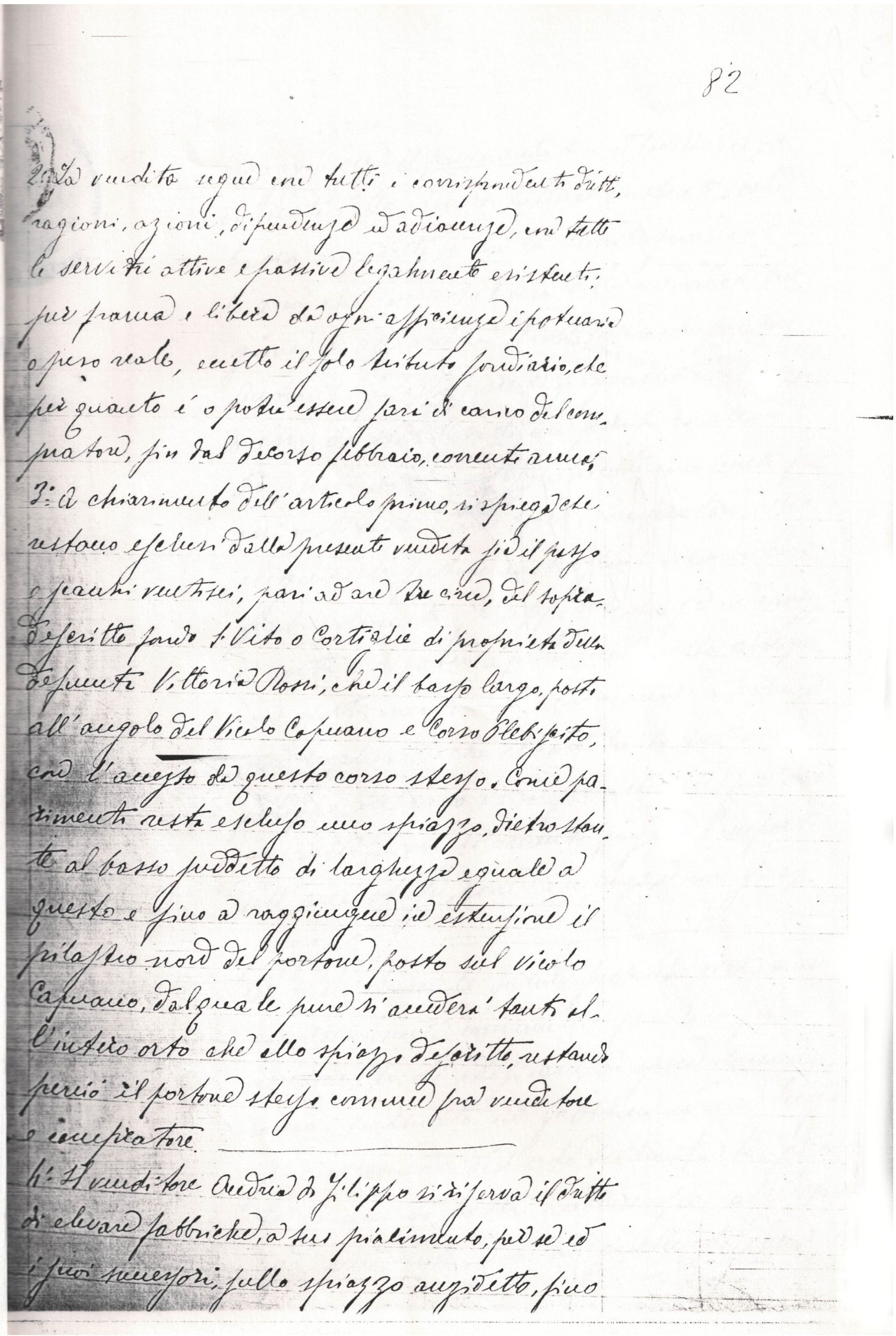

personale io Notaro dichiaro di esser certo a mezzo
delle stesse diretta conoscenza.
Dichiara esso costituito Andrea di Filippo di
essere vero ed assoluto proprietario di alcuni
cespiti urbani e rustici, siti in [illegible], cioè:
a) un fondo rustico denominato [illegible] o San
Vito, della estensione di passi locali ventidue
circa, pari ad are ventisei e centiare qua-
rantaquattro, in piano, confinante con eredi
di Alfonso Botta, con Rosaria Alfano, con Vi-
to di Filippo e Strettola, allo stesso pervenuto
con atti pubblici di data remota in diverse
zone, ed ora riportato nel Catasto terreni di
Piano all'art. 702 folio 5 N. 99, imponibile
lire 66,98.
Di questo fondo, soggiunge esso costituito An-
drea di Filippo, fa parte una zona dell'esten-
sione di passi locali tre e [illegible] ventidue
circa, pari ad are cinque circa, lungo la via pub-
blica, confinante con detta via, con gli eredi di
Alfonso Botta, con Vito di Filippo fu Antonio,
e Strettola, pervenuto al dichiarante ed a sua
moglie Vittoria Rossi, ora defunta, in parti
eguali, dal Russo Maria Gaetana fu Aniello,
con istrumento Notaro Giovanni Galluccio dei

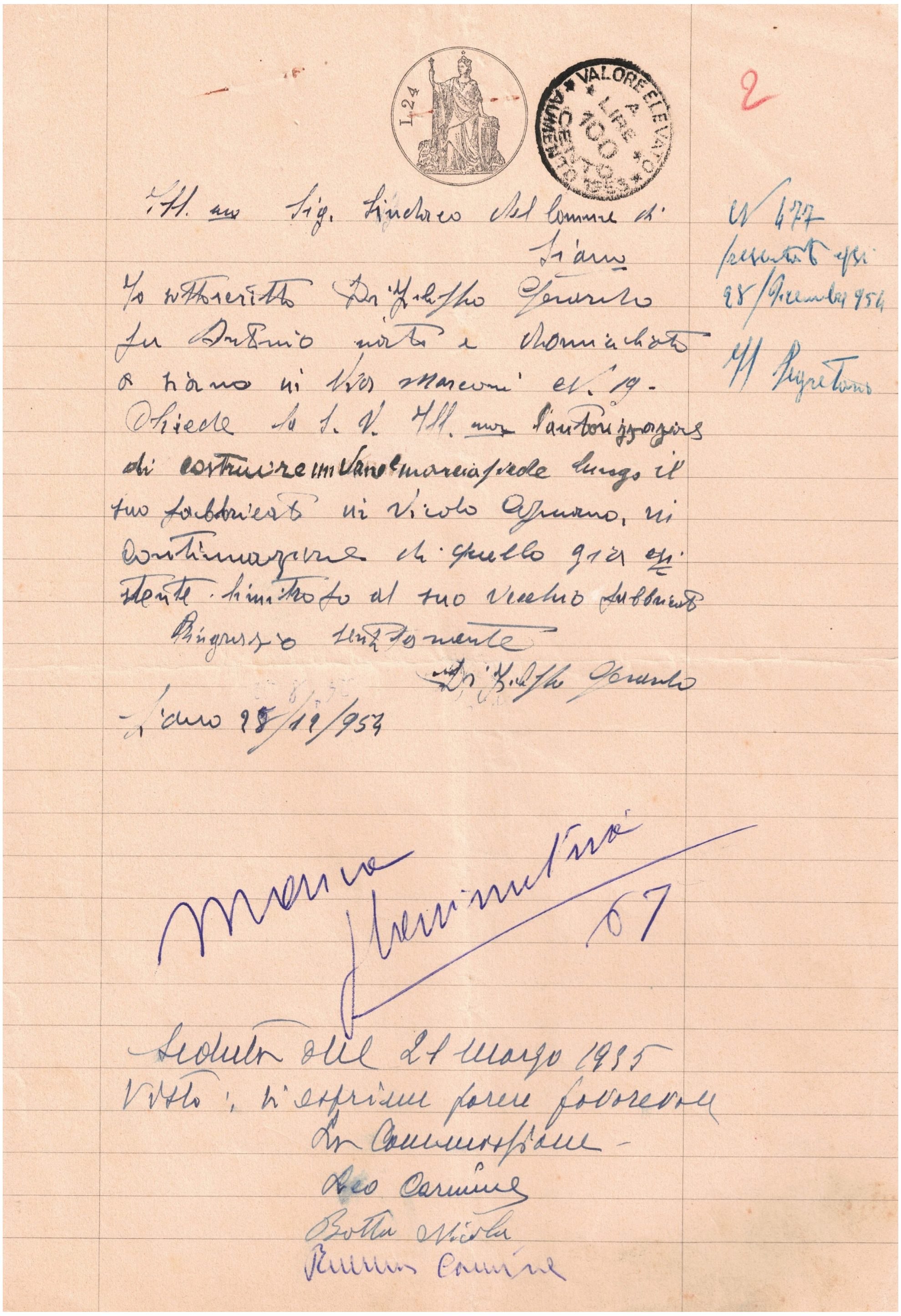
Fig. C. 6. Extract 2 of the deed of sale between family members which allows an approximate dating of the original core of the building block.



82

2: La vendita segue con tutti i corrispondenti diritti,
ragioni, azioni, dipendenze ed adiacenze, con tutte
le servitù attive e passive legalmente esistenti,
per franca e libera da ogni appartenenza ipotecaria
o peso reale, eccetto il solo tributo fondiario, che
per quanto è o potrà essere pari di carico del com-
pratore, fin dal decorso febbraio, corrente anno;
3: A chiarimento dell'articolo primo, si spiega che
restano esclusi dalla presente vendita sia il pezzo
o pezzi ventisei, pari ad are tre circa, del sopra
descritto fondo S. Vito o Cortiglie di proprietà della
defunta Vittoria Rossi; che il basso largo, posto
all'angolo del Vicolo Capuano e Corso Plebiscito,
con l'accesso da questo corso stesso. Come pa-
rimenti resta escluso uno spiazzo, dietrostan-
te al basso predetto di larghezza eguale a
questo e fino a raggiungere in estensione il
pilastro nord del portone, posto sul vicolo
Capuano, dal quale pure si accederà tanto al-
l'intero orto che allo spiazzo descritto, restando
perciò il portone stesso comune fra venditore
e compratore.
4: Il venditore Andrea Di Filippo si riserva il diritto
di elevare fabbriche, a suo piacimento, per sé ed
i suoi successori, sullo spiazzo suddetto, fino

Fig. C. 7. Extract 3 of the deed of sale between family members which allows an approximate dating of the original core of the building block.



L. 24

VALORE ELEVATO A LIRE 100 CENTO AUMENTO 1953

2

Ill.mo Sig. Sindaco del Comune di
Siano

Io sottoscritto Di Filippo Gerardo
fu Antonio nato e domiciliato
a Siano in Via Marconi n. 19.
Chiede a S. V. Ill.ma l'autorizzazione
di costruire un vano marciapiede lungo il
suo fabbricato in Vicolo Agnano, in
continuazione di quello già esi-
stente limitrofo al suo vecchio fabbricato
Ringrazio sentitamente
Di Filippo Gerardo

Siano 28/12/1954

N. 477
presentato oggi
28/Dicembre 1954
Il Segretario

67

Seduta del 21 Marzo 1955
Visto: si esprime parere favorevole
La Commissione -
Aco Carmine
Botta Nicola
Russo Carmine

Fig. C. 8. Building permit (*Autorizzazione alla costruzione*), dated to 28 December 1954, with a favourable opinion of the Municipality of *Siano* dated 21 March 1955.

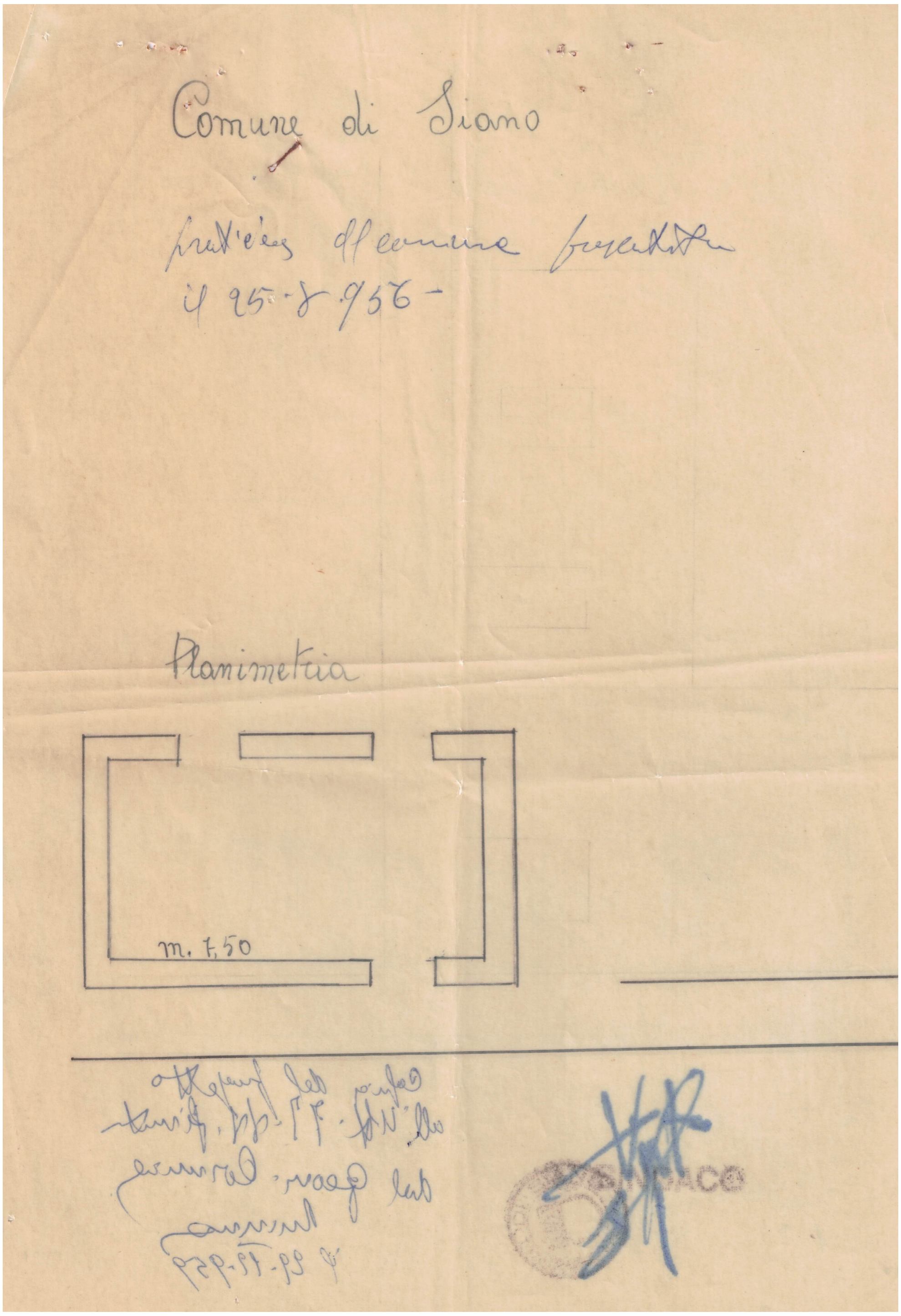


Fig. C. 9. Design of the first extension to the building (plan, 1955-56).

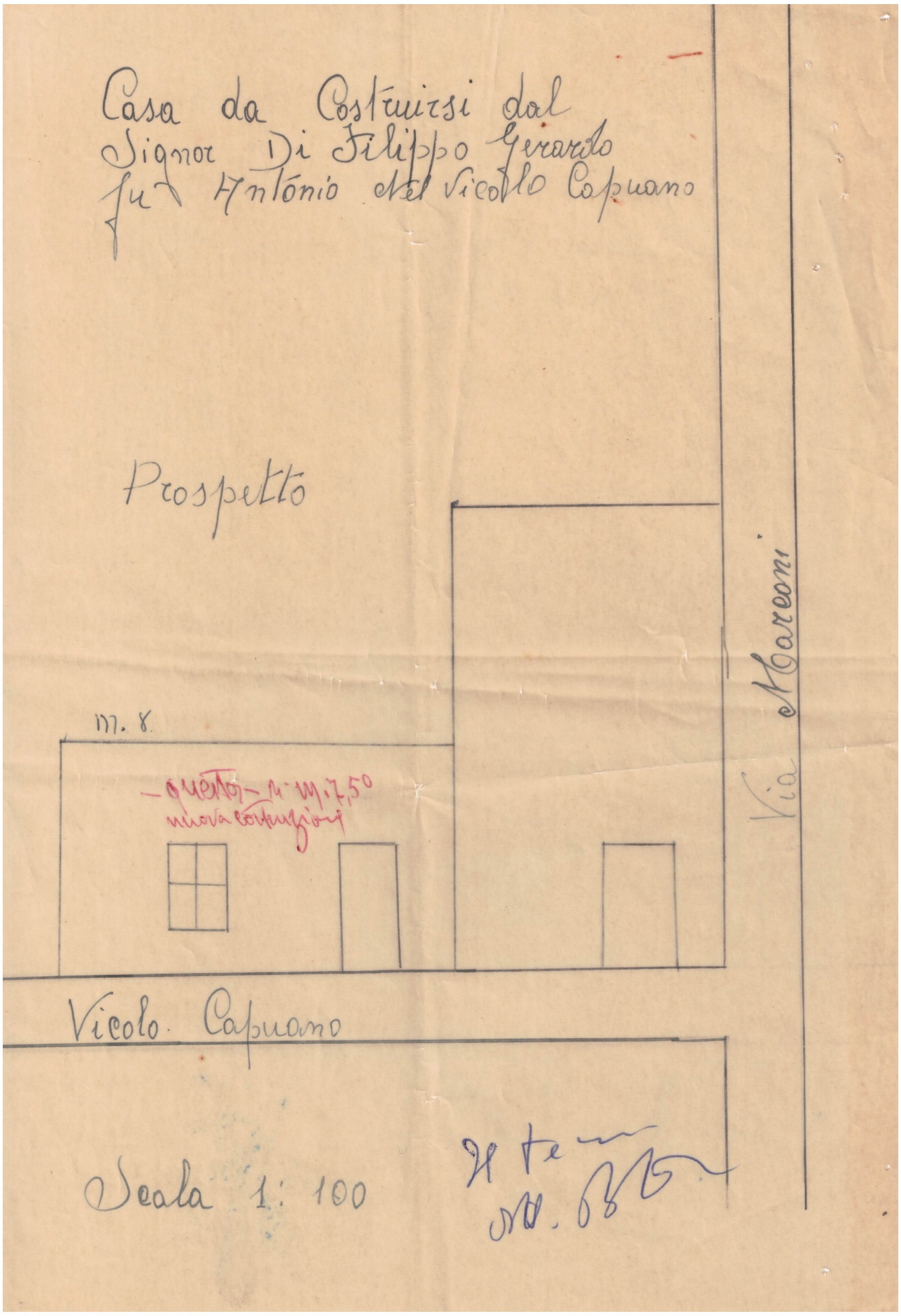
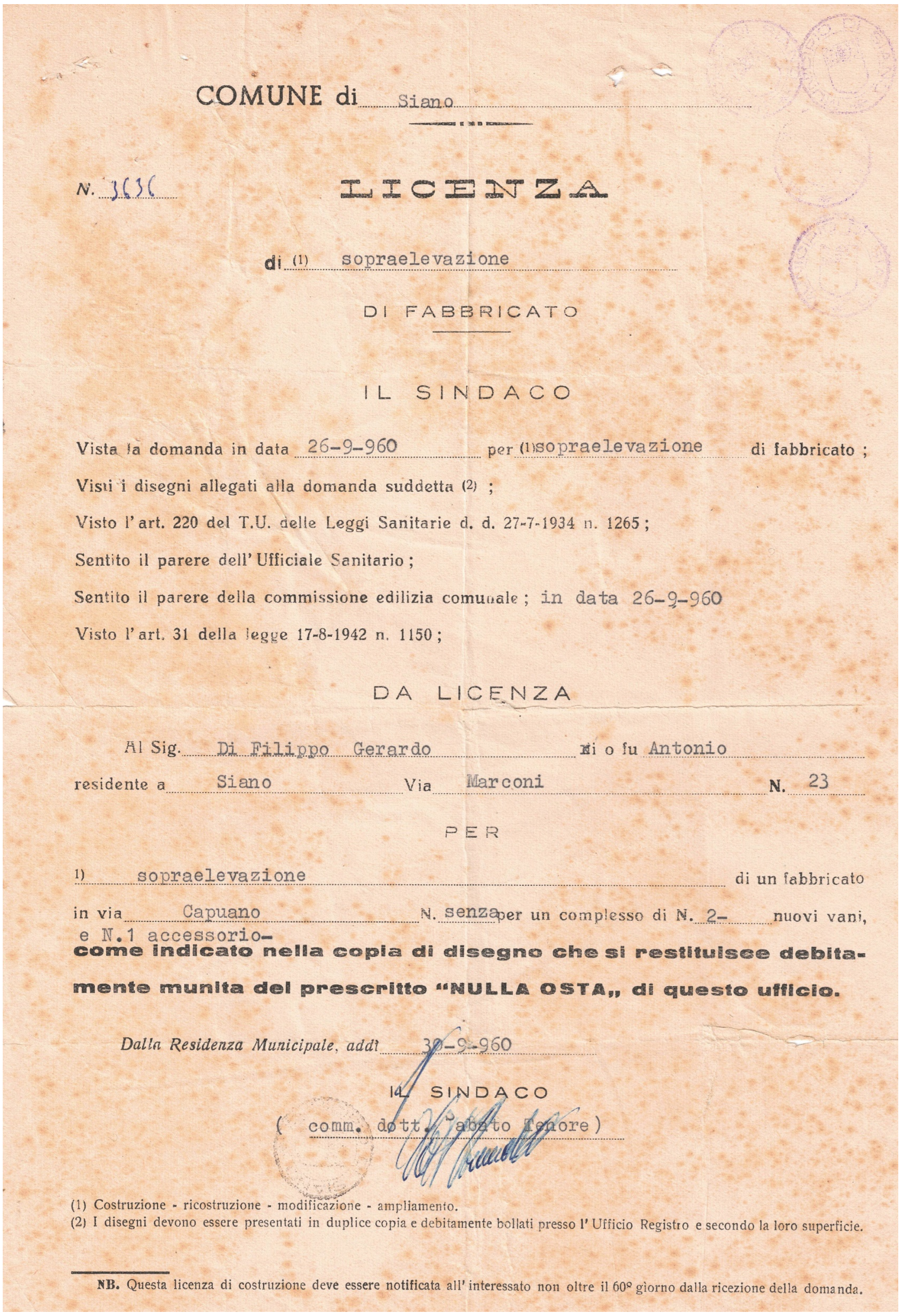


Fig. C. 10. Design of the first extension to the building (facade, 1955-56).



COMUNE di Siano

N. 3636

LICENZA

di (1) sopraelevazione

DI FABBRICATO

IL SINDACO

Vista la domanda in data 26-9-960 per (1) sopraelevazione di fabbricato ;

Visti i disegni allegati alla domanda suddetta (2) ;

Visto l'art. 220 del T.U. delle Leggi Sanitarie d. d. 27-7-1934 n. 1265 ;

Sentito il parere dell'Ufficiale Sanitario ;

Sentito il parere della commissione edilizia comunale ; in data 26-9-960

Visto l'art. 31 della legge 17-8-1942 n. 1150 ;

DA LICENZA

Al Sig. Di Filippo Gerardo di o fu Antonio

residente a Siano Via Marconi N. 23

PER

1) sopraelevazione di un fabbricato

in via Capuano N. senza per un complesso di N. 2- nuovi vani,
e N.1 accessorio-

come indicato nella copia di disegno che si restituisce debitamente munita del prescritto "NULLA OSTA" di questo ufficio.

Dalla Residenza Municipale, addì 30-9-960

IL SINDACO

(comm. dott. Sabato Tenore)

(1) Costruzione - ricostruzione - modificazione - ampliamento.
(2) I disegni devono essere presentati in duplice copia e debitamente bollati presso l'Ufficio Registro e secondo la loro superficie.

NB. Questa licenza di costruzione deve essere notificata all'interessato non oltre il 60° giorno dalla ricezione della domanda.

Fig. C. 11. Planning permission (*Licenza di sopraelevazione*) protocol n° 3636 of 30 September 1960.

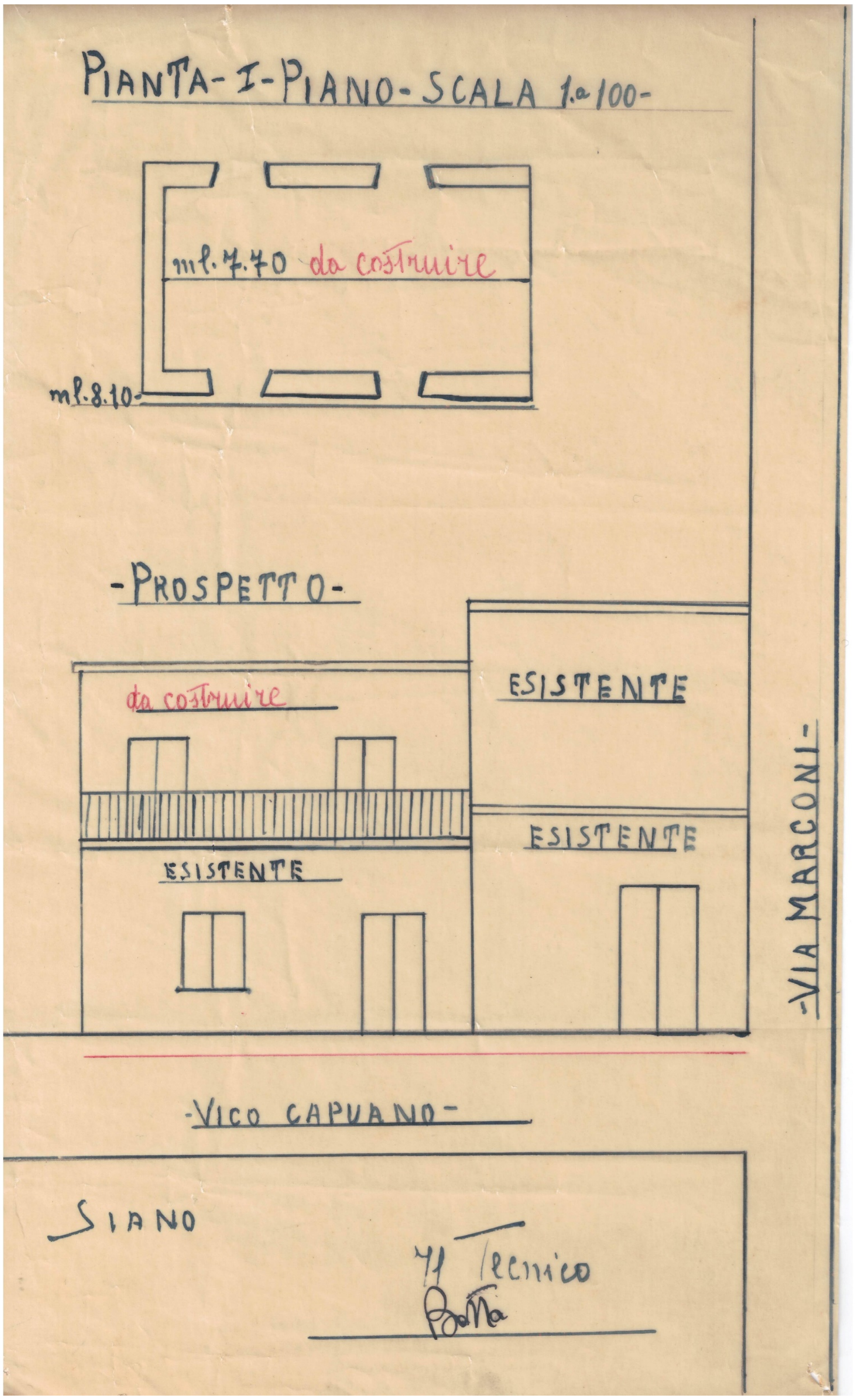
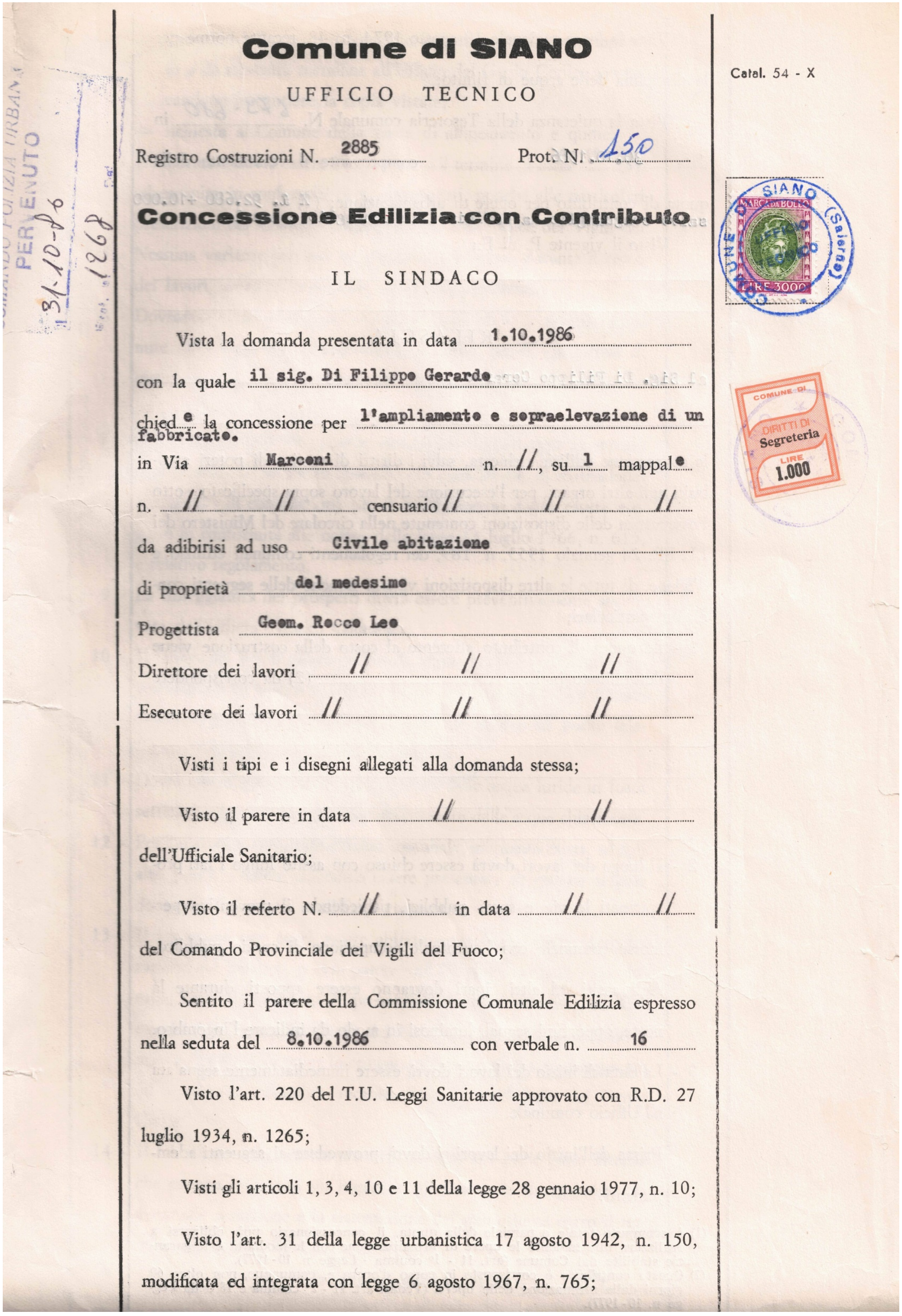


Fig. C. 12. Design of the second extension to the building (1960).



Comune di SIANO

UFFICIO TECNICO

Catal. 54 - X

Registro Costruzioni N. 2885 Prot. N. 150

Concessione Edilizia con Contributo

IL SINDACO

Vista la domanda presentata in data 1.10.1986

con la quale il sig. Di Filippo Gerardo

chiede la concessione per l'ampliamento e sopraelevazione di un fabbricato.

in Via Marconi n. //, su 1 mappale

n. // // censuario // // //

da adibirisi ad uso Civile abitazione

di proprietà del medesimo

Progettista Geom. Rocco Leo

Direttore dei lavori // // //

Esecutore dei lavori // // //

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data // //

dell'Ufficiale Sanitario;

Visto il referto N. // in data // //

del Comando Provinciale dei Vigili del Fuoco;

Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 8.10.1986 con verbale n. 16

Visto l'art. 220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n. 1265;

Visti gli articoli 1, 3, 4, 10 e 11 della legge 28 gennaio 1977, n. 10;

Visto l'art. 31 della legge urbanistica 17 agosto 1942, n. 150, modificata ed integrata con legge 6 agosto 1967, n. 765;

Fig. C. 13. Planning permission (*Concessione edilizia, Registro costruzioni n° 2882, prot. n° 150 del 31 ottobre 1986*).

COMUNE DI SIANO

UFFICIO TECNICO

Registro Costruzioni N. 208 Prot. N. 2885

CONCESSIONE EDILIZIA CON CONTRIBUTO

IL SINDACO

Vista la domanda presentata in data 16.11.92

con la quale i sigg. Leo Adelaide - Di Filippo Maria- Rosa- Rocco - Rita ed Adriana

chiedono la concessione per Riapprovazione e Voltura della concessione edilizia n° 150 del 31.10.1986

in Via Marconi n. ///, su 1 mappale n. 8 censuario 1110-1111-1719

da adibirsi ad uso civile abitazione

di proprietà idem

Progettista Geom. Rocco Leo

Direttore dei lavori // // //

Esecutore dei lavori /// // //

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data 27.11.1992 dell'Ufficiale Sanitario;

Visto il referto N. //// in data /// ///

del Comando Provinciale dei Vigili del Fuoco;

Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 27.11.1992 con verbale n. 16

Visto l'art. 220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n. 1265;

Visti gli articoli 1, 3, 4, 10 e 11 della legge 28 gennaio 1977, n. 10;

Visto l'art. 31 della legge urbanistica 17 agosto 1942, n. 150, modificata ed integrata con legge 6 agosto 1967, n. 765;

Tip. G. Dolgetta - Sarno

Fig. C. 14. Planning permission (*Concessione edilizia, Registro costruzioni n° 208, prot. n° 2885 del 3 dicembre 1992*).

COMUNE DI SIANO

UFFICIO TECNICO

Registro Costruzioni N. 21 Prot. N. 4021

CONCESSIONE EDILIZIA CON CONTRIBUTO

IL SINDACO

Vista la domanda presentata in data 7.12.92

con la quale i sigg. Leo Adelaide-Di Filippo Maria - Rosa - Rocco - Rita ed Adriana

chiedono la concessione per Una Varainte alla concessione edilizia n° 208 del 3.12.1992

in Via Marconi n. //// su 1 mappale n. 8 censuario 1110-1111-1719

da adibirsi ad uso civile abitazione

di proprietà idem

Progettista : Geom. Leo Rocco

Direttore dei lavori Geom. Leo Rocco

Esecutore dei lavori Imp. Rinaldi Ottavio

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data 28.1.93 dell'Ufficiale Sanitario;

Visto il referto N. ////// in data /// /// del Comando Provinciale dei Vigili del Fuoco;

Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 28.1.93 con verbale n. 1

Visto l'art. 220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n. 1265;

Visti gli articoli 1, 3, 4, 10 e 11 della legge 28 gennaio 1977, n. 10;

Visto l'art. 31 della legge urbanistica 17 agosto 1942, n. 150, modificata ed integrata con legge 6 agosto 1967, n. 765;

Tip. G. Dolgetta - Sarno

Fig. C. 15. Planning permission (*Concessione edilizia, Registro costruzioni n° 21, prot. n° 4021 del 15 febbraio 1993*).

COMUNE DI SIANO

UFFICIO TECNICO

Registro Costruzioni N. 99 Prot. N. 4021

CONCESSIONE EDILIZIA CON CONTRIBUTO

IL SINDACO

Vista la domanda presentata in data 10/09/1993

con la quale ~~i Sigg. Rocco - Rita ed Adriana~~ Leo Adelaide-Di Filippo Maria- Rosa-

chied.... la concessione per una proroga alla conc. edilizia n° 208 del 3.12.992 - Variante n° 21 del 15.2.993

in Via Marconi n. /// su 1 mappale

n. 8 censuario 1110 - 1111 - 1719

da adibirsi ad uso civile abitazione

di proprietà idem

Progettista Geom. Leo Rocco

Direttore dei lavori Geom. Leo Rocco

Esecutore dei lavori Imp. Rinaldi Ottavio

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data 28/1/993

dell'Ufficiale Sanitario;

Visto il referto N. // // in data // //

del Comando Provinciale dei Vigili del Fuoco;

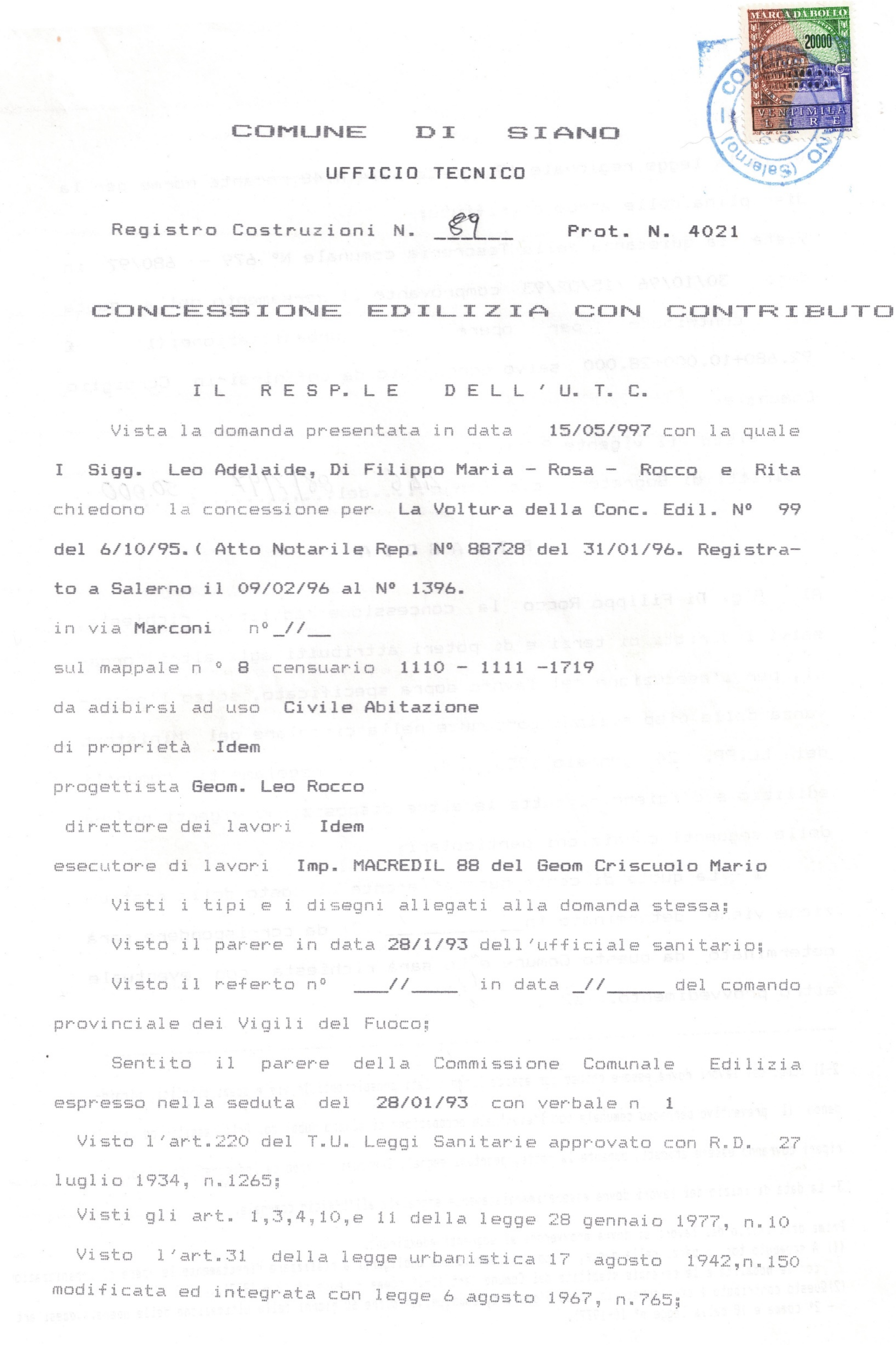
Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 28/1/993 con verbale n. 1

Visto l'art. 220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n. 1265;

Visti gli articoli 1, 3, 4, 10 e 11 della legge 28 gennaio 1977, n. 10;

Visto l'art. 31 della legge urbanistica 17 agosto 1942, n. 150, modificata

Fig. C. 16. Planning permission (*Concessione edilizia, Registro costruzioni n° 99, prot. n° 4021 del 6 ottobre 1995*).



COMUNE DI SIANO

UFFICIO TECNICO

Registro Costruzioni N. 89 Prot. N. 4021

CONCESSIONE EDILIZIA CON CONTRIBUTO

IL RESP.LE DELL'U.T.C.

Vista la domanda presentata in data 15/05/997 con la quale I Sigg. Leo Adelaide, Di Filippo Maria - Rosa - Rocco e Rita chiedono la concessione per La Voltura della Conc. Edil. N° 99 del 6/10/95.(Atto Notarile Rep. N° 88728 del 31/01/96. Registrato a Salerno il 09/02/96 al N° 1396.

in via Marconi n° //

sul mappale n ° 8 censuario 1110 - 1111 -1719

da adibirsi ad uso Civile Abitazione

di proprietà Idem

progettista Geom. Leo Rocco

direttore dei lavori Idem

esecutore di lavori Imp. MACREDIL 88 del Geom Criscuolo Mario

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data 28/1/93 dell'ufficiale sanitario;

Visto il referto n° // in data // del comando provinciale dei Vigili del Fuoco;

Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 28/01/93 con verbale n 1

Visto l'art.220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n.1265;

Visti gli art. 1,3,4,10,e 11 della legge 28 gennaio 1977, n.10

Visto l'art.31 della legge urbanistica 17 agosto 1942,n.150 modificata ed integrata con legge 6 agosto 1967, n.765;

Fig. C. 17. Planning permission (*Concessione edilizia, Registro costruzioni n° 89, prot. n° 4021 del 21 luglio 1997*).

COMUNE DI SIANO

UFFICIO TECNICO

Registro Costruzioni N. 13 Prot. N. 4740

CONCESSIONE EDILIZIA GRATUITA

IL RESP. LE DELL'U. T. C.

Vista la domanda presentata in data ~~18/9/98~~ 18/3/99 con la quale il sig. Di Filippo Rocco chiede la Concessione Edilizia per La ristrutturazione e Manutenzione Straordinaria e la costruzione di una copertura a tetto

via Marconi n/ sul mappale n° 8 Censuario N° 1110/3-6 1111 proprietà idem

Visti i tipi e i disegni allegati alla domanda stessa;

Visto il parere in data 8.3.99 dell'ufficiale sanitario;

Visto il referto n° / / in data / / del comando provinciale dei Vigili del Fuoco;

Sentito il parere della Commissione Comunale Edilizia espresso nella seduta del 26/1/99 e 23/3/99 con verbale n 1 e 3

Visto l'art.220 del T.U. Leggi Sanitarie approvato con R.D. 27 luglio 1934, n.1265;

Visti gli art. 1,3,4, e 9 della legge 28 gennaio 1977, n.10

Visto l'art.31 della legge urbanistica 17 agosto 1942, n. 1150 modificata ed integrata con legge 6 agosto 1967, n.765;

Visto il vigente P. di F.

Diritti di Segreteria c.c.p.n° 0138 del 29/3/99 £. 30.000

Fig. C. 18. Planning permission (*Concessione edilizia, Registro costruzioni n° 13, prot. n° 4740 del 30 marzo 1999*).

- 1-

23 APR. 1999

PROT. N. 21238
DEL 10/11/93
REG. N. 8640

COLLAUDO STATICO

LEGGE 02/02/1974 N. 64 - LEGGE 05/11/1971 N. 1086 - L. R. N. 9/1983

OGGETTO : Collaudo statico relativa alla sopraelevazione di un fabbricato per civile abitazione sito in via Marcone del Comune di Siano.

COMMITTENTE : DI FILIPPO ROCCO - VIA ZAMBRANO -SIANO.

Con nota Reg. 8640 e Prot. 21238 del 10/11/1993 l'Ufficio Regionale del Genio Civile di Salerno comunicava al sottoscritto dr.Ing. Vincenzo Bove ,iscritto all'Ordine degli Ingegneri della Provincia di Salerno al N. 493 da oltre 10 anni,e che non ha partecipato alla progettazione o alla D.L. per il fabbricato in oggetto ,l'incarico di Collaudatore Statico in C.O. del fabbricato.

In data 17/05/1996,Prot. 1040/96 veniva depositata ,dal D.L. geom. Rocco Leo, relazione a struttura ultimata relativa a quanto sopra dichiarato dalla quale si evincevano i seguenti dati:

REGIONE CAMPANIA
SETTORE PROV. DEL GENIO CIVILE
S A L E R N O
DEPOSITATO ai sensi della L.R. 7-1-1983 N. 9 art. 2
Prot. N. 8148 Reg. N. 8640
21 APR. 1999
Salerno
Visto: Il Dirigente del Settore

ATTI DEPOSITATI : 1) PROT. 21238 ,REG. 8640 DEL 10/11/1993
- Progetto architettonico
- Progetto delle strutture
- Relazione geologica tecnica

2) PROT. 1694/96 DEL 28/08/1996
- Relazione a struttura ultimata

Dagli atti suddetti risulta :

COMMITTENTE : DI FILIPPO ROCCO - VIA ZAMBRANO -SIANO

IMPRESA ESECU.: RINALDI OTTAVIO - SIANO - VIA CASA LEO

DIRETT. LAV. : GEOM. ROCCO LEO - SIANO - VIA S. MARIA DELLE GRAZIE

UBICAZIONE DEL FABBRICATO: VIA ~~S. MARIA DELLE GRAZ~~ MARCONI IE - SIANO-

Fig. C. 19. Static inspection following work completed on 23 March 2000.

Appendix D: results of the accuracy assessment

Close-range photogrammetry accuracy assessment
Phase 1: test for normality

Distribution Fitting (Uncensored Data) - Max semi axis k=3

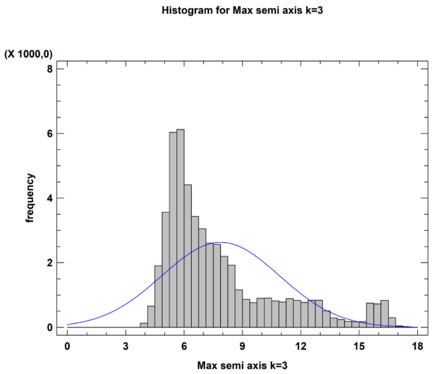
Data variable: Max semi axis k=3

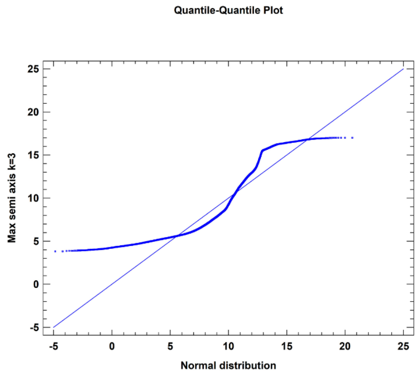
85564 values ranging from 3,819 to 16,995

Fitted Distributions

Normal
mean = 7,88328
standard deviation = 3,02734

The StatAdvisor
This analysis shows the results of fitting a normal distribution to the data on Max semi axis k=3. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





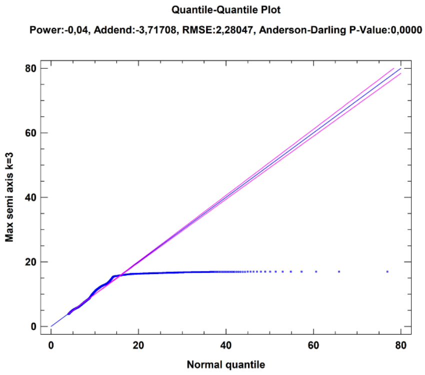
Goodness-of-Fit Tests for Max semi axis k=3
Kolmogorov-Smirnov Test

	Normal
DPLUS	0,150674
DMINUS	0,117521
DN	0,150674
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Max semi axis k=3 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Max semi axis k=3 comes from a normal distribution with 95% confidence.

Phase 2: search for normalizing transformation



Close-range photogrammetry accuracy assessment
Phase 3: alternative distribution fitting

Comparison of Alternative Distributions

Distribution	*Est. Parameters*	*Log Likelihood*	*KS D*
Largest Extreme Value	2	-124318,	0,101821
Inverse Gaussian	2	-124540,	0,104624
Birnbaum-Saunders	2	-124661,	0,10586
Lognormal	2	-124754,	0,102015
Loglogistic	2	-125527,	0,0738683
Gamma	2	-127301,	0,118302
Laplace	2	-132311,	0,162978
Weibull	2	-132918,	0,133218
Logistic	2	-133161,	0,129191
Normal	2	-134568,	0,150674
Uniform	2	-137325,	0,360563
Smallest Extreme Value	2	-146781,	0,20798
Exponential	1	-163228,	0,42059
Pareto	1	-196894,	0,513911

The StatAdvisor
This table compares the goodness-of-fit when various distributions are fit to Max semi axis k=3. You can select other distributions using Pane Options.

According to the log likelihood statistic, the best fitting distribution is the largest extreme value distribution. To fit this distribution, press the alternate mouse button and select Analysis Options.

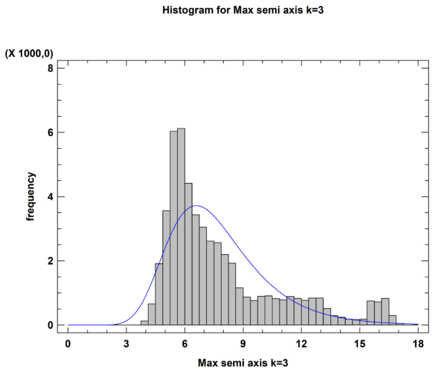
Distribution Fitting (Uncensored Data) - Max semi axis k=3
Data variable: Max semi axis k=3

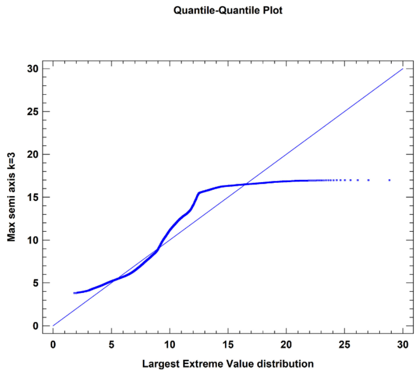
85564 values ranging from 3,819 to 16,995

Fitted Distributions

Largest Extreme Value
mode = 6,59233
scale = 1,97472

The StatAdvisor
This analysis shows the results of fitting a largest extreme value distribution to the data on Max semi axis k=3. The estimated parameters of the fitted distribution are shown above. You can test whether the largest extreme value distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the largest extreme value distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





Goodness-of-Fit Tests for Max semi axis k=3
Kolmogorov-Smirnov Test

	Largest Extreme Value
DPLUS	0,101821
DMINUS	0,0683842
DN	0,101821
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Max semi axis k=3 can be adequately modeled by a largest extreme value distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Max semi axis k=3 comes from a largest extreme value distribution with 95% confidence.

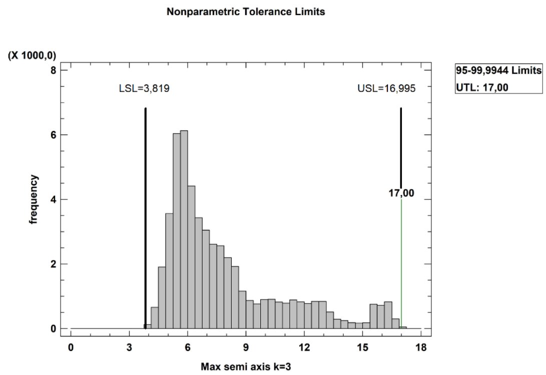
Close-range photogrammetry accuracy assessment
Phase 4: non-parametric tolerance limits

Statistical Tolerance Limits - Max semi axis k=3
Data variable: Max semi axis k=3

Nonparametric Tolerance Limits
sample size = 85564
depth: 1

95,0% tolerance bound for 99,9944% of the population
Upper: 16,995

The StatAdvisor
Without assuming any particular distribution, the tolerance limits state that we can be 95,0% confident that at least 99,9944% of the distribution lies below 16,995.



Considering the length distribution of the major semi-axes for the ellipsoids of error k = 3 associated with the tie points, we obtain an upper tolerance limit of 17.0 mm. Based on the data fed in the photogrammetric process, we can compose the following accuracy label:

$$17.0GA2 \tag{6}$$

UAV photogrammetry accuracy assessment
Phase 1: test for normality

Distribution Fitting (Uncensored Data) - Max semi-axis k=3

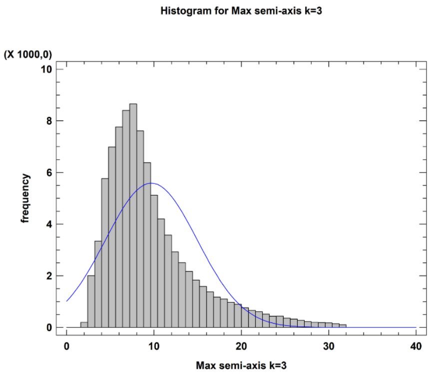
Data variable: Max semi-axis k=3 (mm)

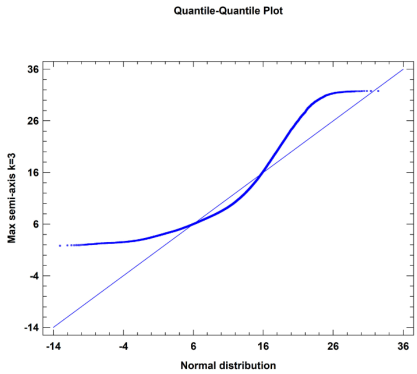
92840 values ranging from 1,831 to 31,785

Fitted Distributions

Normal
mean = 9,69326
standard deviation = 5,25449

The StatAdvisor
This analysis shows the results of fitting a normal distribution to the data on Max semi-axis k=3. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





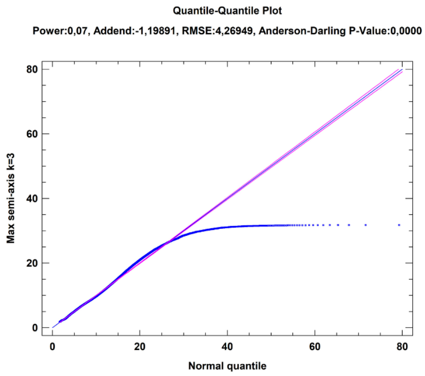
Goodness-of-Fit Tests for Max semi-axis k=3
Kolmogorov-Smirnov Test

	Normal
DPLUS	0,128394
DMINUS	0,0844494
DN	0,128394
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Max semi-axis k=3 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Max semi-axis k=3 comes from a normal distribution with 95% confidence.

Phase 2: search for normalizing transformation



UAV photogrammetry accuracy assessment
Phase 3: alternative distribution fitting

Comparison of Alternative Distributions

Distribution	*Est. Parameters*	*Log Likelihood*	*KS D*
Inverse Gaussian	2	-264115,	0,0282983
Birnbaum-Saunders	2	-264227,	0,0328413
Lognormal	2	-264328,	0,0285486
Loglogistic	2	-265356,	0,0227047
Largest Extreme Value	2	-266868,	0,0487233
Gamma	2	-267121,	0,063783
Weibull	2	-272715,	0,0878984
Laplace	2	-277401,	0,104955
Logistic	2	-278708,	0,0849115
Normal	2	-283174,	0,128394
Exponential	1	-300968,	0,278915
Smallest Extreme Value	2	-308436,	0,200298
Uniform	2	-312766,	0,427581
Pareto	1	-359263,	0,416231

The StatAdvisor
This table compares the goodness-of-fit when various distributions are fit to Max semi-axis k=3. You can select other distributions using Pane Options.

According to the log likelihood statistic, the best fitting distribution is the inverse Gaussian distribution. To fit this distribution, press the alternate mouse button and select Analysis Options.

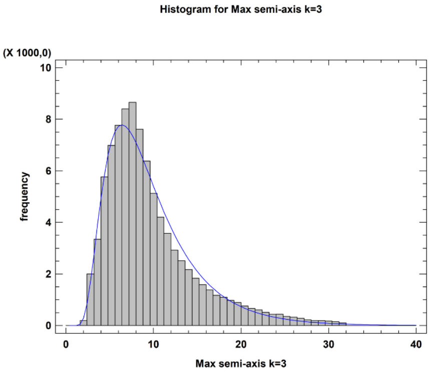
Distribution Fitting (Uncensored Data) - Max semi-axis k=3
Data variable: Max semi-axis k=3 (mm)

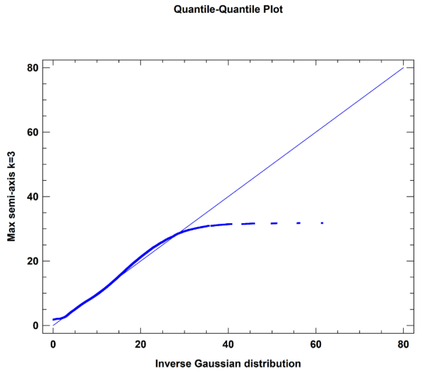
92840 values ranging from 1,831 to 31,785

Fitted Distributions

Inverse Gaussian
mean = 9,69326
scale = 3,50255

The StatAdvisor
This analysis shows the results of fitting an inverse Gaussian distribution to the data on Max semi-axis k=3. The estimated parameters of the fitted distribution are shown above. You can test whether the inverse Gaussian distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the inverse Gaussian distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





Goodness-of-Fit Tests for Max semi-axis k=3
Kolmogorov-Smirnov Test

	Inverse Gaussian
DPLUS	0,0282983
DMINUS	0,0138616
DN	0,0282983
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Max semi-axis k=3 can be adequately modeled by an inverse Gaussian distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Max semi-axis k=3 comes from a inverse Gaussian distribution with 95% confidence.

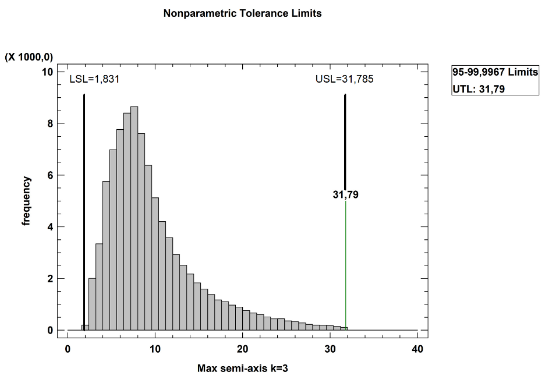
UAV photogrammetry accuracy assessment
Phase 4: non-parametric tolerance limits

Statistical Tolerance Limits - Max semi-axis k=3
Data variable: Max semi-axis k=3 (mm)

Nonparametric Tolerance Limits
sample size = 92840
depth: 1

95,0% tolerance bound for 99,9967% of the population
Upper: 31,785

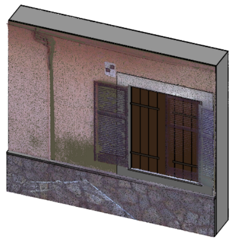
The StatAdvisor
Without assuming any particular distribution, the tolerance limits state that we can be 95,0% confident that at least 99,9967% of the distribution lies below 31,785.



Considering the length distribution of the major semi-axes for the ellipsoids of error k = 3 associated with the tie points, we obtain an upper tolerance limit of 31.8 mm. Based on the data fed in the photogrammetric process, we can compose the following accuracy label:

$$31.8GA2 \tag{7}$$

Modelled accuracy assessment: Wall_01
Phase 1: test for normality



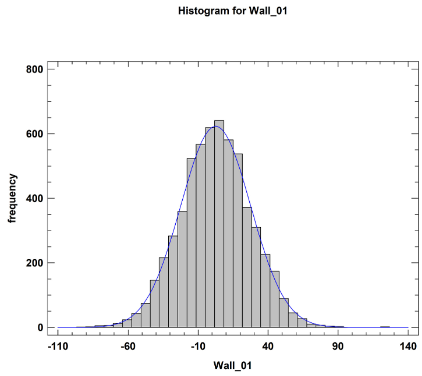
Distribution Fitting (Uncensored Data) - Wall_01
Data variable: Wall_01 (mm)

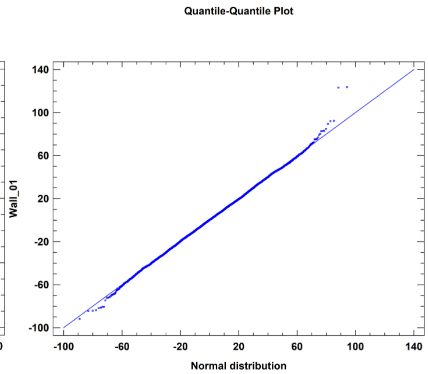
5912 values ranging from -91,78 to 123,56

Fitted Distributions

Normal
mean = 2,59118
standard deviation = 24,8884

The StatAdvisor
This analysis shows the results of fitting a normal distribution to the data on Wall_01. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.



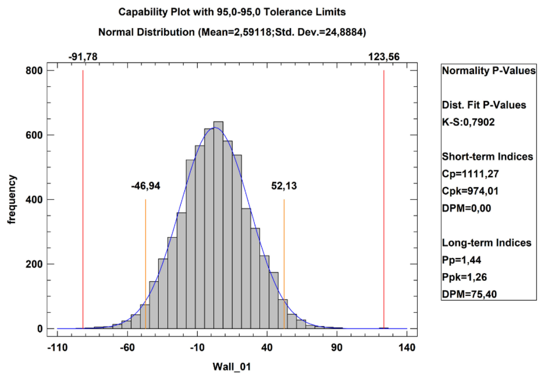


Goodness-of-Fit Tests for Wall_01
Kolmogorov-Smirnov Test

	Normal
DPLUS	0,00846873
DMINUS	0,00727347
DN	0,00846873
P-Value	0,790219

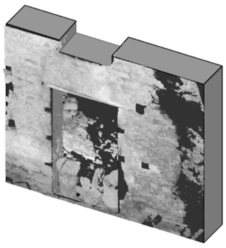
The StatAdvisor
This pane shows the results of tests run to determine whether Wall_01 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is greater than or equal to 0,05, we can not reject the idea that Wall_01 comes from a normal distribution with 95% confidence.



$$\text{Modelled accuracy reference label: } 52.1LRD2 \tag{8}$$

Modelled accuracy assessment: Wall_02
Phase 1: test for normality



Distribution Fitting (Uncensored Data) - Wall_02

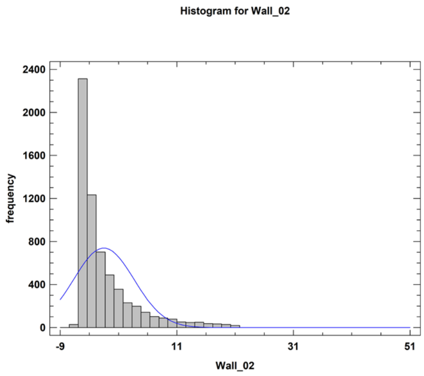
Data variable: Wall_02 (mm)

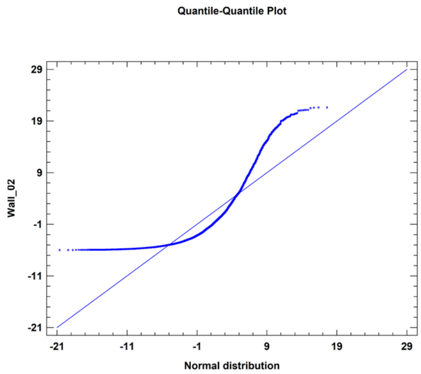
6233 values ranging from -5,98 to 21,63

Fitted Distributions

Normal
mean = -1,52731
standard deviation = 5,17195

The StatAdvisor
This analysis shows the results of fitting a normal distribution to the data on Wall_02. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





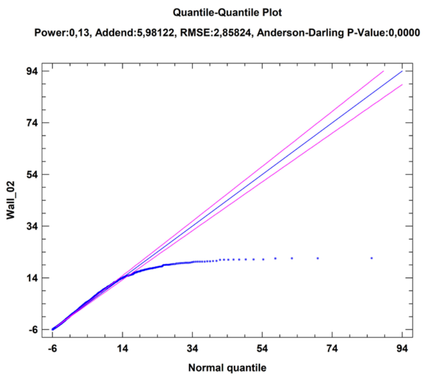
Goodness-of-Fit Tests for Wall_02
Kolmogorov-Smirnov Test

	Normal
DPLUS	0,180006
DMINUS	0,195009
DN	0,195009
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Wall_02 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Wall_02 comes from a normal distribution with 95% confidence.

Phase 2: search for normalizing transformation



Modelled accuracy assessment: Wall_02
Phase 3: alternative distribution fitting

Comparison of Alternative Distributions

Distribution	Est. Parameters	Log Likelihood	KS D
Largest Extreme Value	2	-17229,8	0,134032
Laplace	2	-18139,7	0,244639
Logistic	2	-18482,9	0,197537
Normal	2	-19086,1	0,195009
Uniform	2	-20682,2	0,545102
Inverse Gaussian	2	-20682,2	
Smallest Extreme Value	2	-21149,0	0,301112
Loglogistic	2	-1,E9	0,754051
Exponential	1	-6,241E12	1,41434E6
Lognormal	2	-6,241E12	0,76851
Weibull	2	-6,241E12	0,89365
Gamma	2	-6,241E12	
Pareto	1	-6,241E12	1995,39
Birnbaum-Saunders	<no fit>		

The StatAdvisor
This table compares the goodness-of-fit when various distributions are fit to Wall_02. You can select other distributions using Pane Options.

According to the log likelihood statistic, the best fitting distribution is the largest extreme value distribution. To fit this distribution, press the alternate mouse button and select Analysis Options.

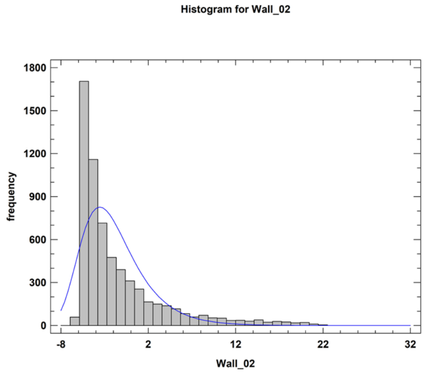
Distribution Fitting (Uncensored Data) - Wall_02
Data variable: Wall_02 (mm)

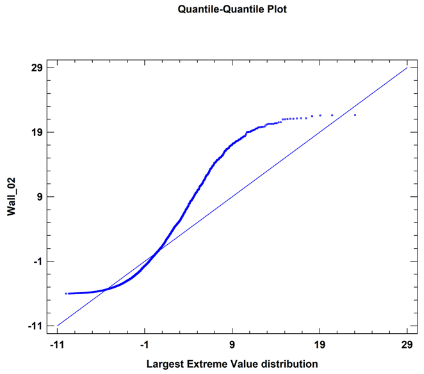
6233 values ranging from -5,98 to 21,63

Fitted Distributions

Largest Extreme Value
mode = -3,55129
scale = 2,91805

The StatAdvisor
This analysis shows the results of fitting a largest extreme value distribution to the data on Wall_02. The estimated parameters of the fitted distribution are shown above. You can test whether the largest extreme value distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the largest extreme value distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





Goodness-of-Fit Tests for Wall_02
Kolmogorov-Smirnov Test

	Largest Extreme Value
DPLUS	0,134032
DMINUS	0,101825
DN	0,134032
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Wall_02 can be adequately modeled by a largest extreme value distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Wall_02 comes from a largest extreme value distribution with 95% confidence.

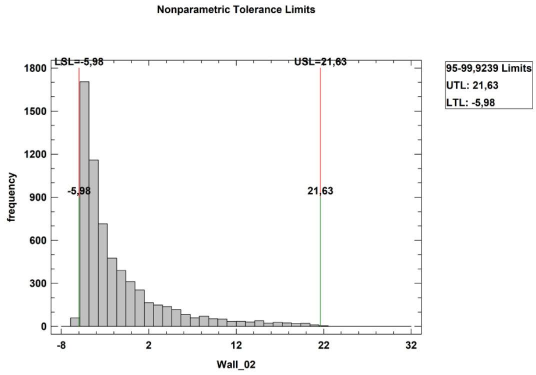
Modelled accuracy assessment: Wall_02
Phase 4: non-parametric tolerance limits

Statistical Tolerance Limits - Wall_02
Data variable: Wall_02 (mm)

Nonparametric Tolerance Limits
sample size = 6233
depth: 1

95,0% tolerance interval for 99,9239% of the population
Upper: 21,63
Lower: -5,98

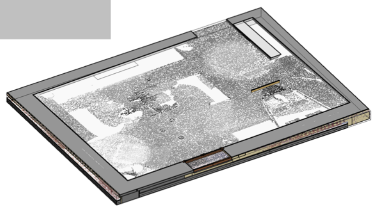
The StatAdvisor
Without assuming any particular distribution, the tolerance limits state that we can be 95,0% confident that at least 99,9239% of the distribution lies between -5,98 and 21,63.



Considering the distribution of distances between the BIM object and the corresponding reality-based integrated model, we can compose the following accuracy label:

$$21.6LRD2 \tag{9}$$

Modelled accuracy assessment: Slab_01
Phase 1: test for normality



Distribution Fitting (Uncensored Data) - Slab_01

Data variable: Slab_01 (mm)

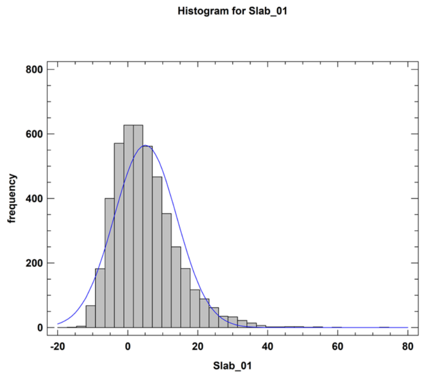
4689 values ranging from -14,8996 to 73,2059

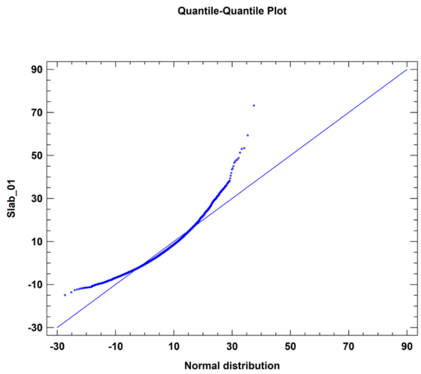
Fitted Distributions

Normal
mean = 5,06029
standard deviation = 8,94761

The StatAdvisor

This analysis shows the results of fitting a normal distribution to the data on Slab_01. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





Goodness-of-Fit Tests for Slab_01

Kolmogorov-Smirnov Test

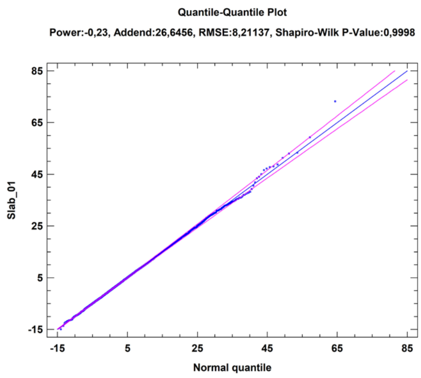
	Normal
DPLUS	0,0656484
DMINUS	0,0463887
DN	0,0656484
P-Value	0,0

The StatAdvisor

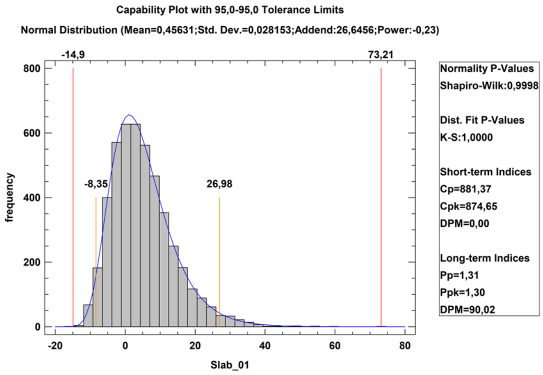
This pane shows the results of tests run to determine whether Slab_01 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Slab_01 comes from a normal distribution with 95% confidence.

Phase 2: search for normalizing transformation



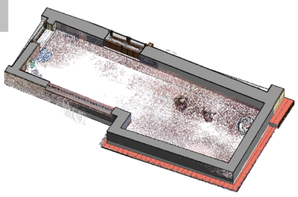
Modelled accuracy assessment: Slab_01
Phase 2: search for normalizing transformation



Considering the distribution of distances between the BIM object and the corresponding reality-based integrated model, we can compose the following accuracy label:

$$24.9LRD2 \tag{10}$$

Modelled accuracy assessment: Slab_02
Phase 1: test for normality



Distribution Fitting (Uncensored Data) - Slab_02

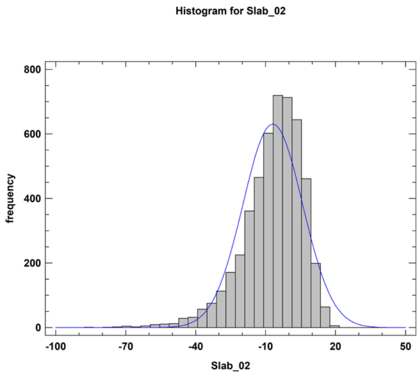
Data variable: Slab_02

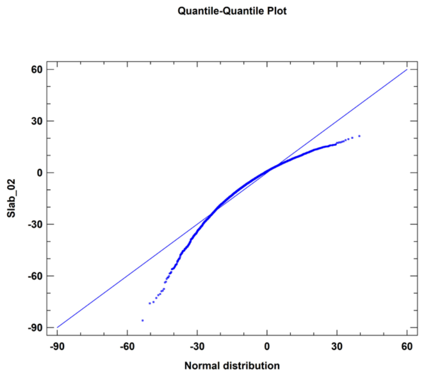
4983 values ranging from -85,8533 to 21,2229

Fitted Distributions

Normal
mean = -6,9181
standard deviation = 12,7757

The StatAdvisor
This analysis shows the results of fitting a normal distribution to the data on Slab_02. The estimated parameters of the fitted distribution are shown above. You can test whether the normal distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the normal distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





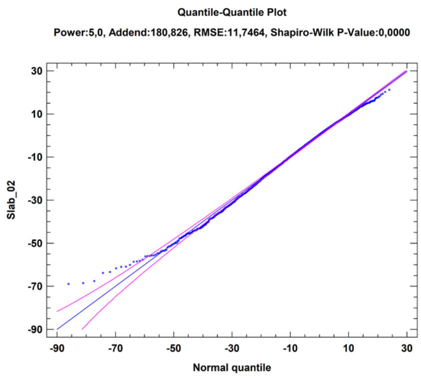
Goodness-of-Fit Tests for Slab_02
Kolmogorov-Smirnov Test

	Normal
DPLUS	0,0472222
DMINUS	0,0693616
DN	0,0693616
P-Value	0,0

The StatAdvisor
This pane shows the results of tests run to determine whether Slab_02 can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is less than 0,05, we can reject the idea that Slab_02 comes from a normal distribution with 95% confidence.

Phase 2: search for normalizing transformation



Modelled accuracy assessment: Slab_02
Phase 3: alternative distribution fitting

Comparison of Alternative Distributions

Distribution	Est. Parameters	Log Likelihood	KS D
Smallest Extreme Value	2	-19323,4	0,00597687
Loglogistic	2	-19323,4	
Logistic	2	-19626,0	0,0469041
Laplace	2	-19725,9	0,0623573
Normal	2	-19764,5	0,0693616
Uniform	2	-23288,3	0,482775
Inverse Gaussian	2	-23288,3	
Exponential	1	-4,983E12	21,4932
Lognormal	2	-4,983E12	0,74066
Weibull	2	-4,983E12	0,970579
Gamma	2	-4,983E12	
Pareto	1	-4,983E12	5,03227E7
Largest Extreme Value	<no fit>		
Birnbaum-Saunders	<no fit>		

The StatAdvisor
This table compares the goodness-of-fit when various distributions are fit to Slab_02. You can select other distributions using Pane Options.

According to the log likelihood statistic, the best fitting distribution is the smallest extreme value distribution. To fit this distribution, press the alternate mouse button and select Analysis Options.

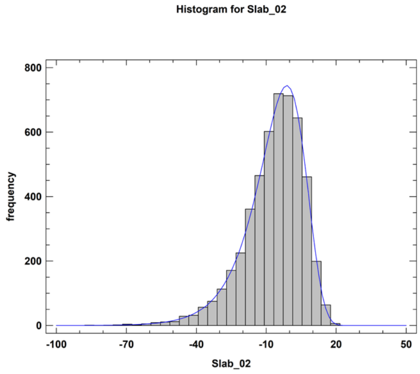
Distribution Fitting (Uncensored Data) - Slab_02
Data variable: Slab_02

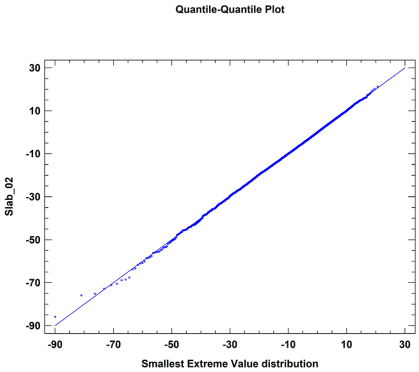
4983 values ranging from -85,8533 to 21,2229

Fitted Distributions

Smallest Extreme Value
mode = -1,16512
scale = 9,98211

The StatAdvisor
This analysis shows the results of fitting a smallest extreme value distribution to the data on Slab_02. The estimated parameters of the fitted distribution are shown above. You can test whether the smallest extreme value distribution fits the data adequately by selecting Goodness-of-Fit Tests from the list of Tabular Options. You can also assess visually how well the smallest extreme value distribution fits by selecting Frequency Histogram from the list of Graphical Options. Other options within the procedure allow you to compute and display tail areas and critical values for the distribution. To select a different distribution, press the alternate mouse button and select Analysis Options.





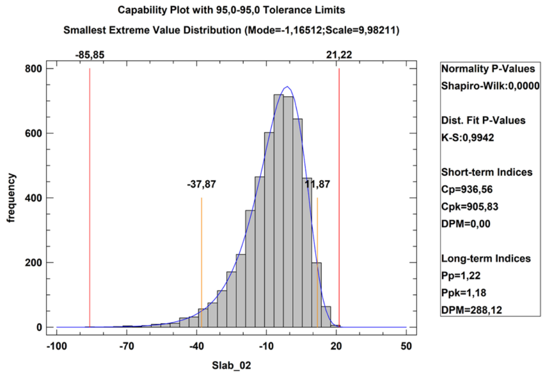
Goodness-of-Fit Tests for Slab_02
Kolmogorov-Smirnov Test

	Smallest Extreme Value
DPLUS	0,00597687
DMINUS	0,00571683
DN	0,00597687
P-Value	0,994193

The StatAdvisor
This pane shows the results of tests run to determine whether Slab_02 can be adequately modeled by a smallest extreme value distribution.

Since the smallest P-value amongst the tests performed is greater than or equal to 0,05, we can not reject the idea that Slab_02 comes from a smallest extreme value distribution with 95% confidence.

Modelled accuracy assessment: Slab_02
Phase 3: alternative distribution fitting



Considering the distribution of distances between the BIM object and the corresponding reality-based integrated model, we can compose the following accuracy label:

$$37.9LRD2 \tag{11}$$

“Si può imparare qualcosa da un temporale.
Quando un acquazzone ci sorprende, cerchiamo di non bagnarci affrettando il passo,
ma anche tentando di ripararci sotto i cornicioni ci inzuppiamo ugualmente.
Se invece, sin dal principio, accettiamo di bagnarci eviteremo ogni incertezza
e non per questo ci bagneremo di più.
Tale consapevolezza si applica a tutte le cose.”

Dall’Hagakure