Integration and BIM digitization of interdisciplinary research and diagnostic campaigns for knowledge and conservation: Palazzo Vecchio in Florence

Anna Livia Ciuffreda | annalivia.ciuffreda@unifi.it
Department of Earth Sciences, University of Florence
Massimo Coli | massimo.coli@unifi.it
Department of Earth Sciences, University of Florence
Marco Tanganelli | marco.tanganelli@unifi.it
Department of Architecture, University of Florence
Giorgio Verdiani | giorgio.verdiani@unifi.it
Department of Architecture, University of Florence

Abstract
This work reports the results of a multidisciplinary research project concerning the historical complex of Palazzo Vecchio in Florence. This building of exceptional size is the result of successive evolutions starting from the thirteenth century in an area that has been urbanized since the Roman age. The study, which aimed at assessing the seismic vulnerability of the complex, required the completion of numerous sub-phases for the architectural and structural characterization of the building: the identification of the structural units, the historical research, the architectural and structural geometric survey, the study of the subsoil and the integration of non-destructive or partially destructive diagnostic campaigns. The creation of a three-dimensional parametric model (BIM) has allowed the computerized management of data from the knowledge acquisition process and its use for the analysis of seismic vulnerability, for the facility management of the complex and for the creation of virtual museum itineraries.

Keywords
Cultural heritage, Palazzo Vecchio, HBIM, Informative models.

Introduction

Acquiring accurate knowledge about the morphology, the material characteristic and the historical evolution of any built heritage is a fundamental step in its preservation. In the cases of extremely complex buildings whose various developments cover a long time span, this obvious assertion may not be easily satisfied; even using contemporary digital tools and exploiting the extreme quality and versatile opportunities offered by advanced instruments, these subjects present very articulated challenges.

This is the case of Palazzo Vecchio in Florence, Italy. The need to assess its seismic behaviour made it imperative to obtain solid knowledge of the structures and materials of the building in perfect accordance with the provisions of the Guidelines 2011[1] (LG) and e NTC 2018[2]. Starting from documentary research and a complete and accurate 3D digital survey[3], an extensive non-destructive testing (NDT) campaign was then carried out that involved the whole complex. The deepening and multiplication of information from the knowledge acquisition process required the management of data according to innovative and systematic methodologies. In this sense,

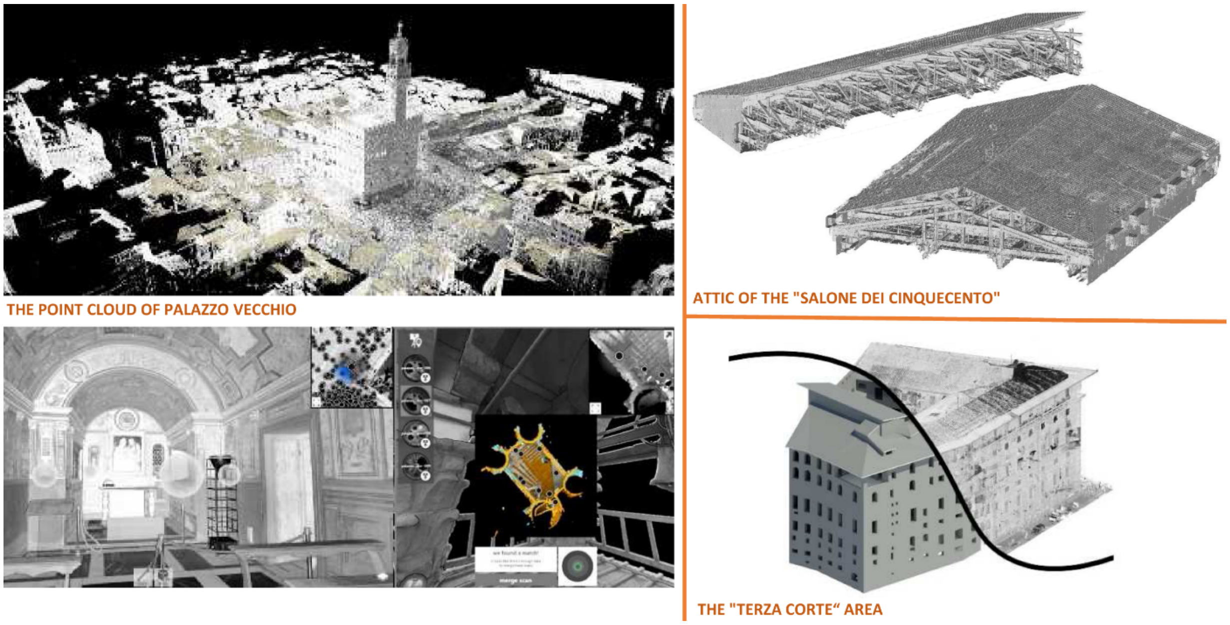

Fig. 1 The phases of elaboration of the point cloud of Palazzo Vecchio (from the theses by Francesca Meli, Agnese Gasparotti, and Beatrice Fossatelli)

the Palazzo Vecchio case study represented an excellent opportunity to experiment with the application of innovative methodologies, such as BIM, for building knowledge management [4].

In 2018 as part of a research agreement between the University of Florence (Department of Architecture, Department of Earth Sciences) and the Municipality of Florence, the required history research, survey and diagnostic phases began, accompanied by the experimentation of the application of BIM to this very particular case study.

In this paper will describe the methods, approaches, and results of this experimental research, which represents a perfect example of multidisciplinary activity and collaboration between different research fields, and which is still ongoing.

The digital Survey

When talking about a complex survey like the one of Palazzo Vecchio, maybe it is better to start from the end. The resulting data set, which aimed to provide a proper base for the seismic analysis, was completed with about 5500 single scans, an amount of data equivalent to 1,3 Terabyte of information. This extremely large dataset needed optimization. In fact, the resampled "light-weight" version of the dataset was resampled according to a grid of one centimetre, producing a simplified point cloud of "just" 80 Gigabyte. These provided the basis for the start of the production of traditional CAD drawings and the basis for a specific modelling in Autodesk Revit (Fig. 1).

A large number of scans was needed to cover the whole building, which has many large and highly detailed spaces as well as extremely small and narrow spaces, fragmented and transformed rooms, and spaces carved into large older walls. The whole survey required about 21 days to be completed, using up to four different 3D laser scanner units at a time. All the scanners utilized employed phase-shift and were capable of creating coloured point clouds. Due to the specific use of the survey, there was a preference for keeping all the scans in grayscale without using the photographic feature and thus improving the operational speed by not gathering an additional set of data of no use for seismic risk evaluation. Some photographic scans were taken from the roof of the Arnolfo's tower and in the "Salone dei Cinquecento" (the main hall) for performance/quality checking.

Sampling and material analysis

The knowledge acquisition process carried out for Palazzo Vecchio followed various phases as indicated by LG and NTC 2018. The historical-critical analysis of the building was performed through bibliographic and archival research aimed at understanding the historical evolution of the building with particular attention to the changes undergone by the structural system. The history and construction evolution of Palazzo Vecchio was drawn up through the study of the authors who have studied and written about it in the past and the analysis of the available iconography. In this way, the main transformations that the block has undergone over the centuries have been defined.

The data from the historical analyses was superimposed on the data derived from a survey of the current geometry of the building. The latter was obtained by performing laser scanner surveys in such a way as to identify the structures belonging to the various eras.

In particular, the LG draw attention to the historical and construction knowledge of the property and allow indirect non-destructive investigation techniques (thermography, georadar, sonic, etc.) or weakly destructive direct inspections (DAC-Test, endoscopy, plaster removal, essays, penetrometric and sclerometric tests).

In Palazzo Vecchio, the application of non-destructive investigation techniques made it possible to obtain information on construction techniques, wall textures, the presence of occult elements, and to produce first estimates of the resistance of its elements. The execution of a second phase of weakly destructive investigations allowed the reduction of the number of destructive investigations and the calibration of the results of non-invasive investigations, leading to a qualitative judgment of the various elements of the structural system.

Additionally, among the input data there is also the study of the lithostratigraphic structure of the subsoil and of the geo-technical characteristics of the soils, which complete the knowledge acquisition process.

Towards a model for BIM uses

One of the main tasks in the development of the digital representation of Palazzo Vecchio was updating the drawings describing the whole building. This quite traditional processing was done by extracting the horizontal sections from the point cloud and then matching these extremely accurate representations with the previous CAD drawing. This simple task yielded a progressive and consistent updating and enhancement of all the drawings. This created a "new" starting point in which all the walls are correctly represented with their cavities and consistency and the building is shown in its real aspect with the many juxtapositions, restorations, carving changes, overlapping construction phases, and excavations that have happened over time up to its present state.

If the creation of an updated starting point was a necessity, the subsequent logical and important task was to relate these investigations to all the information about the structures.

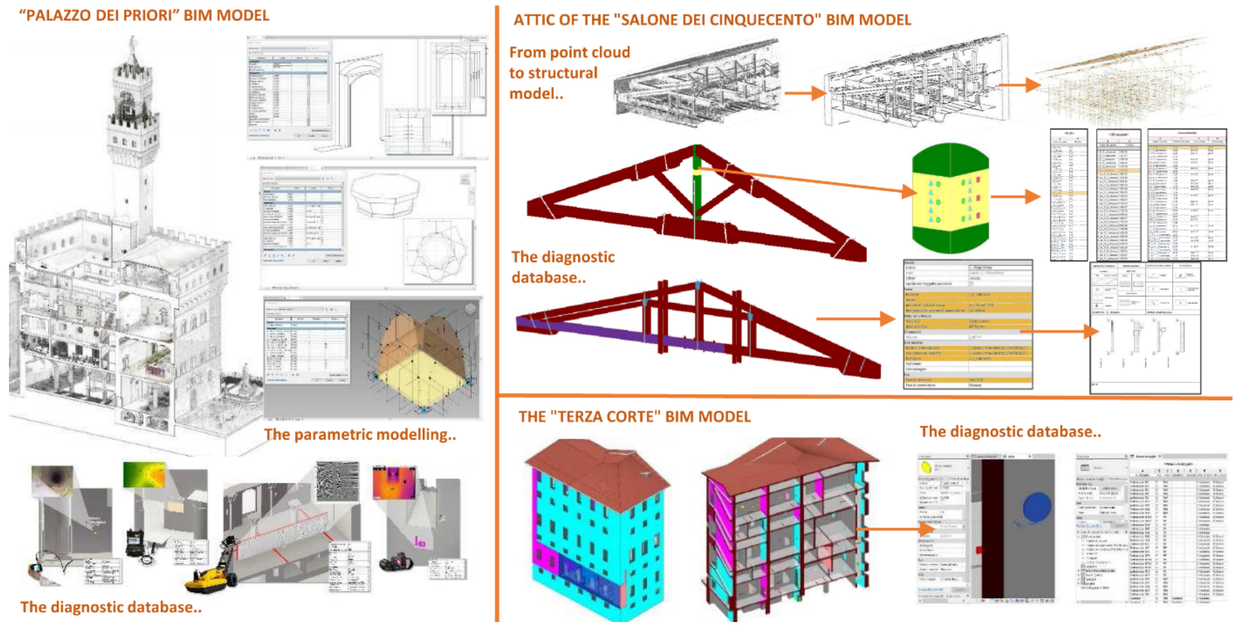

Fig. 2 The BIM models of Palazzo Vecchio: parametric modeling and database for knowledge (from the theses by Francesca Meli, Agnese Gasparotti and Beatrice Fossatelli)

The studies and diagnostic campaigns of a large building such as Palazzo Vecchio produced a considerable amount of data that required a well-structured organization and management of knowledge. In the case of Palazzo Vecchio, this phase involved an initial cataloguing of the data and then its organization using traditional methodologies such as sheets, tables, etc. However, these methods did not relate the object to the information in an easy and intuitive manner, as they had to work through codes and references to 2D drawings. Therefore, it was decided to operate using BIM methodology to test its potential for managing information related to cultural heritage or the possibility of creating a 3D information 'container'.

Examples of 'information models' for the management of cultural heritage are present in the panorama of international research: the '2D or 3D geometric container'[5] is used to store information relating to the life of the building, the state of conservation, the phases of intervention and maintenance.

Through three thesis experiences in the Architecture degree course of the University of Florence, a first experimentation was started for the creation of a single information model of Palazzo Vecchio. The three examples concern the "Palazzo dei Priori" (Arnolfian nucleus), the "Terza Corte", and the wooden structures of the roof of the "Salone dei Cinquecento" (Fig. 2).

In these cases, the entire digitization process was tested: i) the potential of 3D modelling from the point cloud; ii) methods of data storage; iii) methods of querying and implementing the database; iv) interoperability with structural calculation software.

The three-dimensional modelling of Palazzo Vecchio presented the difficulties common to all cultural heritage buildings. The unique and irregular shapes of some structures make it difficult to adapt parameterization to various geometric contexts. The use of adaptive families has helped to overcome such geometric difficulties and the result has provided different LODs depending on the characteristics of the modelled structures and which in any case is between LOD 200 and LOD 300[6].

The insertion of the investigations into the model was carried out by inserting objects into customized families. The geometry of the objects representing the investigations has been studied according to the characteristics of the investigation: for example, it is natural to associate symbols that visually refer to the type of investigation they represent.

The association of information was made using specific parameters that allow users to view the date of execution, the description, the tool used, and the results, as well as other data relating, for example, to the classification of masonry. Each object in the model, from the wall to the investigations, has been provided with an ID that identifies it and which can be viewed within an abacus that allows the model to be queried. The abacus can be filtered and sorted based on parameters, making it easier to query a very complex model like this one. In addition, the management of the phases allows you to view the evolution of the building's construction and the subsequent interventions made to it.

The three experiments carried out had different intentions and produced different results:

- In the case of the "Palazzo dei Priori", the modelling went into detail, covering decorative and architectural elements such as columns, capitals, and coffered ceilings. These can become objects to which information relating to maintenance and restoration can be connected; in addition to diagnostic investigations, the database includes information relating to the assessment of LV1 seismic vulnerabilities, the building's evolutionary phases, and dynamic monitoring system.
- The case of the "Terza Corte" represents the first experimentation in chronological order and is the first attempt to insert a large dataset of diagnostic information in an area of the building with a complex planimetric articulation. This study includes information relating to the assessment of LV1 and LV2 for seismic vulnerabilities and to the building's evolutionary phases.
- The case of the attic of the "Salone dei Cinquecento" resulted in a detailed modelling of the wooden trusses and a first approach to digitizing the surveys and the diagnostic campaign and to exporting the analytical model to a structural calculation software. This experience is the first BIM model of the attic structures for implementing the diagnostic result and programming the maintenance and conservation activity.

The experiences described show that such an approach to 'knowledge management' is already possible and that the ability to read simultaneously all the information relating to an element makes possible a true multidisciplinarity.

Conclusions

The Palazzo Vecchio in Florence is a highly interesting case study of Cultural Heritage, and this article details the laser scanning survey and the subsequent digitisation and archiving procedure utilising BIM methodology. The result is a 3D model that depicts, starting from the "Palazzo dei Priori", how these datasets can be directed to the production of optimized models for BIM uses. The resulting 3D model represents the building in its current geometric state and presents information about the building's evolution, interventions, previous and ongoing research, and monitoring in an understandable and accessible manner.

The development of the information system has made it possible to: (I) Define a 3D model on which to place the diagnostic studies, and (II) study the constructive evolution of the building using a quick and simple phase visualisation. The BIM model has also been a helpful tool in this specific instance for the creation of an active database that enables the development of a model for the management and conservation of an extremely valuable structure from our historical heritage.

The future development of the research will include the completion of the database and its export to web platforms or Open-BIM solutions for consultation so as to make it a freely available resource for operators, scholars, and students in the spirit Open Source.

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[1] Cfr. MIBACT (2011), "Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale allineate alle nuove Norme tecniche per le costruzioni (d.m. 14 gennaio 2008)" (in Italian)

[2] Cfr. NTC (2018), "Aggiornamento delle «Norme tecniche per le costruzioni». G.U. No. 42 del 20 Febbraio D.M. Ministero Infrastrutture e Trasporti 17 gennaio 2018, Roma (in Italian). NTC (2008) Norme tecniche per le costruzioni. D.M. Ministero Infrastrutture e Trasporti 14 gennaio 2008", G.U.R.I. 4 febbraio 2008, Rome, (in Italian).

[3] Cfr. Giorgio Verdiani, *Digital survey: from new technology to everyday use, a knowledge path and challenge for scholars.* «EGE Revista De Expresión Gráfica En La Edificación», 11, 2019, pp. 94–105. Available at https://polipapers.upv.es/index.php/ege/article/view/12873

[4] Cfr. Massimo Coli, Anna Livia Ciuffreda, Tessa Donigaglia, *Informative models for the cultural heritage buildings: applications and case histories*, «Reuso 2019 Patrimonio in divenire», 2019, pp. 421–432, Cfr. Massimo Coli, Anna Livia Ciuffreda, Michelangelo Micheloni, *An informative content 3d model for the hall holding the Resurrection of Christ by Piero della Francesca mural painting at Sansepolcro, Italy.* «ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», XLII-2/W11, 2019, pp. 435-442, 10.5194/isprs-archives-XLII-2-W11-435-2019.

[5] Cfr. Niccolò Iandelli, Massimo Coli, Tessa Donigaglia & Anna Livia Ciuffreda, *An Unconventional Field Mapping Application: A Complete Opensource Workflow Solution Applied to Lithological Mapping of the Coatings of Cultural Heritage.* «International Journal of Geo-Information» 2021, 10, 357 https://doi.org/10.3390/ijgi10060357; Malinverni Eva Savina, Fabio Mariano, Francesco Di Stefano, Leonardo Petetta, Federica Onori, *Modelling in HBIM to document materials decay by a thematic mapping to manage the cultural heritage: the case of "Chiesa della Pietà" in Fermo*, «Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.», XLII-2/W11, 2019, pp. 777-784, https://doi.org/10.5194/isprs-archives-XLII-2-W11-777-2019.

[6] The LOD gives the degree of reliability of both the information integrated into the model: level of detail of the geometry and level of information, cfr. Bim Forum, Level Of Development (LOD), Specification Part I & Commentary For Building Information Models and Data, December 2021.