View of Courtyard of Magnolias inside University of Pavia's Palazzo Centrale (source: DAdaLab).

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3D survey and semantic analysis for the documentation of built heritage. The case study of Palazzo Centrale of Pavia University

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ABSTRACT

In the procedures regarding built heritage documentation, the process of representing the object in a digital environment is characterized by a high level of complexity. In fact, the need to process heterogeneous information, referring to quantity, quality and format is one of the main emerging issues. Recent technologies of digitization of our built environment offer excellent performances on data reliability and time of acquisition. On the other hand, they bring about new challenges regarding how to define methodologies and strategies to effectively elaborate such information.

A possible way to optimize the use of these data is by implementing them into informative systems: these tools have great potential in the creation of multi-layered representations and offer extensive possibilities for interpretations and analyses.

This research, carried out by the laboratories DAdaLab and PLAY of the University of Pavia, focuses on the University's Palazzo Centrale and aims at developing a precise methodological approach: starting from the 3D acquisition, the survey data are discretized – through critical processes of semantic analysis and breakdown – and later implemented into informative databases.

Moreover, the architectural characters, construction phases and the strong bond with the urban setting make the case study particularly valuable; therefore, it represents an excellent opportunity to point out the potentials of this approach to the definition of management tools for the conservation of built heritage.

KEYWORDS

3D information systems, semantic breakdown, built heritage digitization, built heritage management, University of Pavia

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1. INTRODUCTION

The discipline of architectural survey has always been playing a role of scientific and technical methodology, guiding all the fundamental processes of knowledge of an object and how it relates to its context.
As stated by Niglio "Any form of knowledge presupposes a technological attitude, supported by a cognitive and, at the same time, critical ability capable of guiding and responding best to the cultural needs of the time" (Niglio, 2017).
The development of digital acquisition technologies, started at the beginning of the 80s, certainly had a strong impact on this discipline.
The growing use of laser scanner and photogrammetry technologies inevitably shifted the surveyor's attention towards the most purely technical aspects of this process of knowledge (Paris te al., 2017).
The ever-increasing use of these tools brings about new issues related to the necessity to structure and organize databases to contain digital representation data.
The massive diffusion of tridimensional models is one of the most critical aspects: they undoubtedly offer a much easier and more intuitive representation of the real object and all its complexities. Meanwhile, they also require to re-think the support media of the representation, since the two-dimensional drawing is not able to transmit all the information contained in the tridimensional model.
On the other hand, there is a tremendous growth in the amount of data acquired during the survey: these data are extremely complete and heterogeneous and enrich the knowledge of the object referring to quantity and quality. This circumstance raises the need for virtual databases in which more and more real-world information can be injected.
Therefore, growing importance is given to the

Figure 1.
In the foreground, the courtyards of Palazzo Centrale and the facade of Aula Magna, in the backgound the historic core of Pavia.

process of organizing and cataloging acquired data into digital environments that must be structured and interoperable.
This approach to the documentation of architectural artifacts, characterized by the use of tridimensional informative databases, has been implemented in the case study of University of Pavia's Palazzo Centrale.
This architectural complex is characterized by an articulated layout of spaces with different architectural styles and a considerable extension. It is, therefore, an excellent case study since, as well as any other extensive monumental complex, it requires a well-reasoned program of conservation and management.
The operations of integrated survey led to generate an organic and continuous system comprising of all the dimensional and material information; the result is a documentation base on which to build the process of knowledge.
Alongside the acquisition, the data have been organized thanks to a semantic ratio, based on the required analysis; at the same time, the process of technological analysis determined the construction elements of the building, supporting the development of an informative system for the management of the complex, to be subsequently supplemented with further analyses.
These processes have been an excellent field test for a methodology of discretization and cataloging data, whose aim is to create an information database that can be queried and enriched over time. The objective of the research is to demonstrate the potential of this approach and the methodological structure used for the purposes of documentation and management of a particularly vast and complex building (Morandotti te al., 2019).
This tool will be able to simplify the operations of conservation by planning the monitoring and the interventions, with special attention to the optimization of the resources.

2. A METHODOLOGICAL APPROACH TO THE DISCRETIZATION AND MANAGEMENT OF DATA

Back in 1972, Abraham Moles stated that the quantity of information in architecture is drastically raising, but the level of the description techniques is significantly lower compared to its original form. Therefore, representing architecture in a three-dimensional space not only helps to visualize and memorize information more intuitively, but it is also helpful in defining and clarify data in order to represent them (Moles, 1972).
It is well known that when we deal with the built heritage, the survey phase produces a big amount of data. The operators of the documentation procedures are required to work on this data and address their need to be processed, discretized and organized.
In this context, the action of drawings is already an act of discretization: the documentation of architectural artifacts is, in fact, traditionally based on the two-dimensional representation of the object's appearance.
This action still represents the "elected instrument" of the architect in their critical operations of breakdown, interpretation and recomposition of the architectural object (Bianchini, 2016). Nevertheless, it sometimes offers a limited point of view with regards to the complexity of the whole object and its relationships with its surrounding context. Therefore, several issues arise about how to fully represent the complexity and meaning of the architecture.
Furthermore, every building with a high historical and architectural relevance has its stronger feature in its uniqueness: built heritage is the result of a process of transformation carried on over different epochs; each aesthetic and constructive element is also part of a system, forming unique relationships and influenced by traditions and historical events of that specific context.
All these features are extremely hard to appreciate when the representation is limited to a quantitative point of view.
In response to this, a digital three-dimensional model of the building allows to understand and analyze the

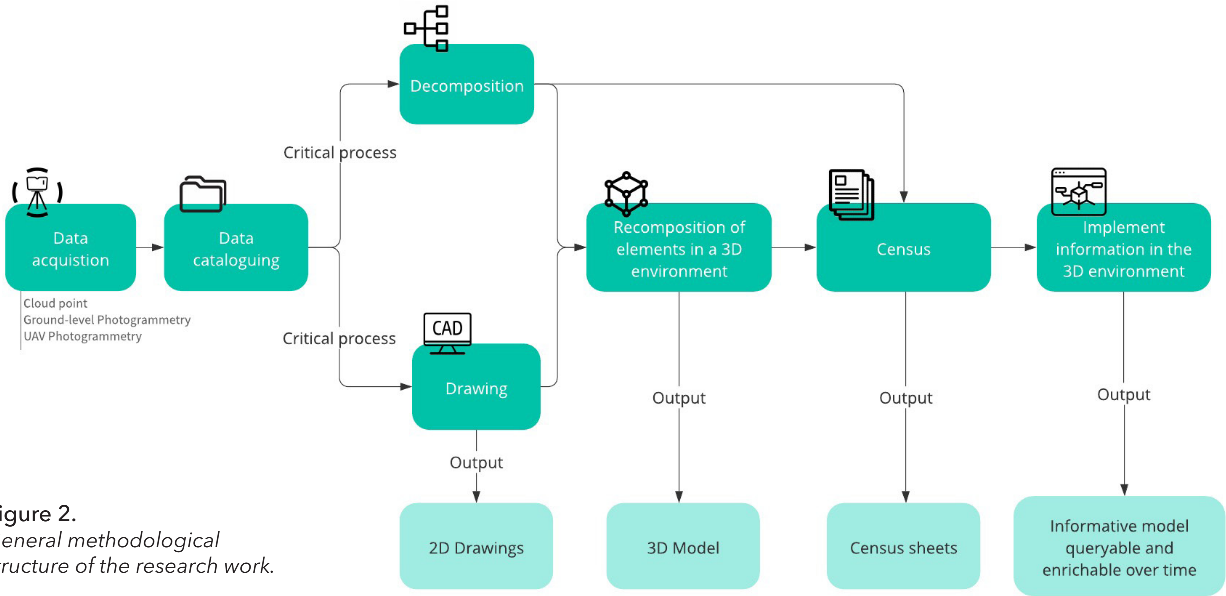


Figure 2.
General methodological structure of the research work.

architecture not just as a set of separated parts but within an overall view. Furthermore, it is possible to deepen the analysis, reaching an adequate level of detail and creating thematic visualizations based on the semantic level to be highlighted.
In order to make it possible, the model must contain all the necessary information (dimensional, morphological and chromatic) to serve as a base for the analyses aiming to enrich and complete the level of knowledge of the object.
Three-dimensional informative systems thus represent flexible and easy to integrate tools, able to fully encompass the meaning of the building and contain the information obtained from the different disciplines involved in the analyses.
The transition to informative systems is also encouraged by EUPPD 2014/24/EU (European Union Public Procurement Directive), which recommends the application of a precise approach to the entire building process: the use of informative systems, particularly referring to BIM, should be pursuit both in new constructions and in conservation and management interventions (Bianchini et al., 2016).
The directive effectively confirmed the growing implementation of the BIM approach to the management of architectural heritage, as many case studies, below mentioned, have been showing.
Some experiences focused on the implementation of heritage-specific metadata in the BIM model, as the case of Soldi Palace in Cremona, where a clear and complete representation of the stratigraphy, historical layers and construction techniques of the building was obtained (Oreni et al., 2011).
Other studies implemented HBIM processes in the parametric modelling starting from laser scanning and photogrammetry. This is the case of the Botany

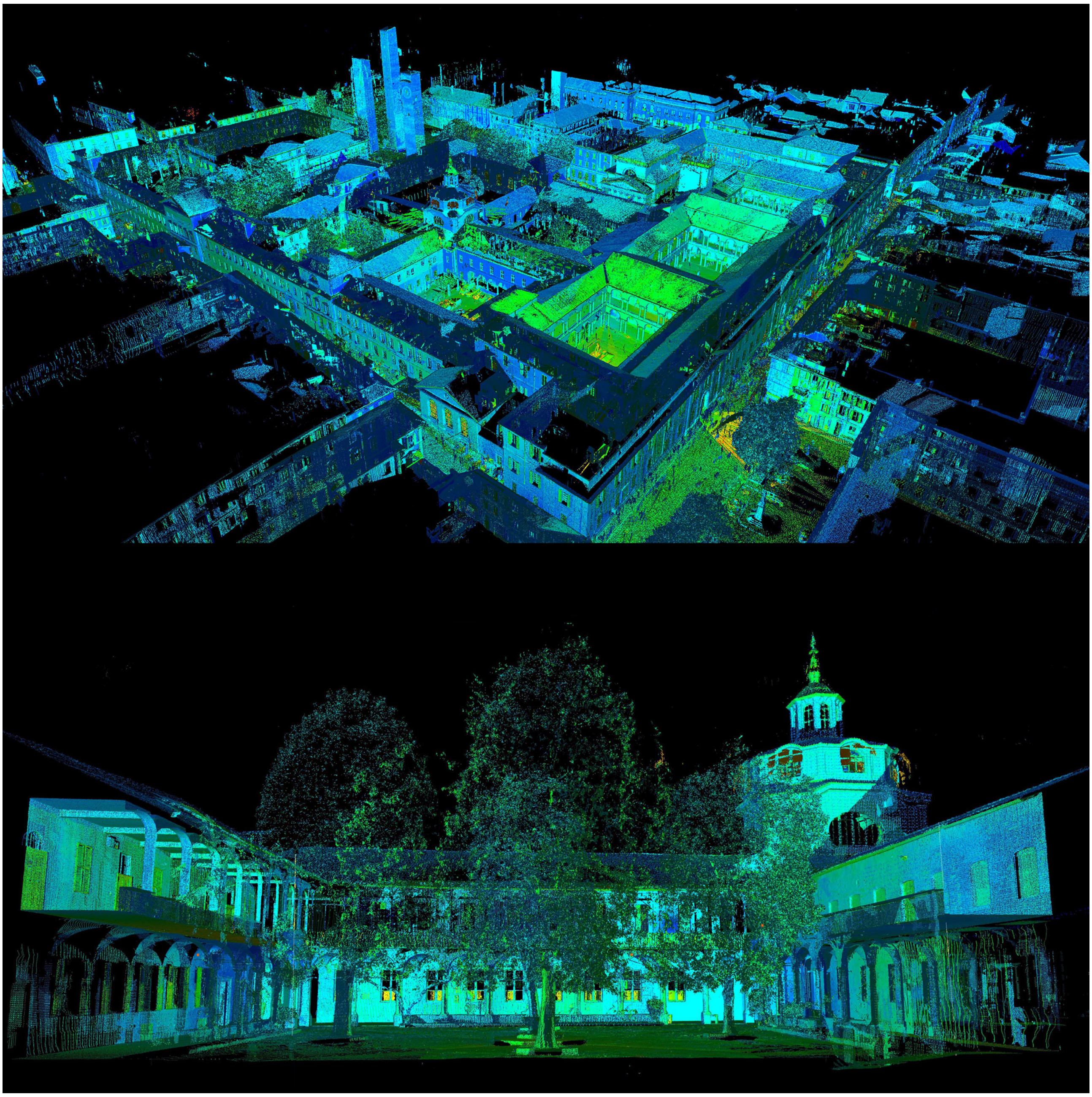


Figure 3.
Perspective views of the cloud point obtained from the digital acquisition.

Institute of Sapienza University and the Temple of Divo Claudio in Rome, (Attenni, 2019), and the Santa Maria degli Angeli alle Croci complex in Naples (Giannattasio et al., 2019), that highlighted the standardisation issues that arise when dealing with profoundly different types of built heritage.
A similar experience has been carried on the Mezquita Baths of the Alhambra, Granada, where accurate BIM models are being developed to investigate and witness the transformations and restoration interventions undergone on the built heritage (Parrinello et al., 2019).
As shown by this brief review, informative systems allow to access various information, different for quality and format. They not only become a fundamental support to process and manage a massive amount of data, but they can also be seen as a united means of data exchange between different operators.
One of the most powerful features of these tools is the ability to enhance manoeuvrability and efficiency by creating relations between different levels of detail in the model.
The extensive use of GIS and BIM informative systems had a strong impact on how we process survey data: the result is that the breakdown of the architectural elements becomes the key phase of the entire process of data integration in these environments.
For example, the point cloud, the main output of the digital survey, needs to be read and interpreted in order to be implemented in an overarching system in which the properties are highlighted thanks to a semantic reading.
The process of breakdown brings to identifying recurring elements, resulting in a standardization necessary to preserve the efficiency of the informative system.
At the same time, the action of discretization must not result in an excessive simplification. Built heritage is characterized by a diversified ensemble, both in terms of geometry and semantic (Yang, 2019): it is, therefore, still fundamental to support the process with the dimensional data deriving from the survey, in order to preserve the reliability of the model in case of imperfections, non-symmetrical elements, or alterations caused by poor conservation status.

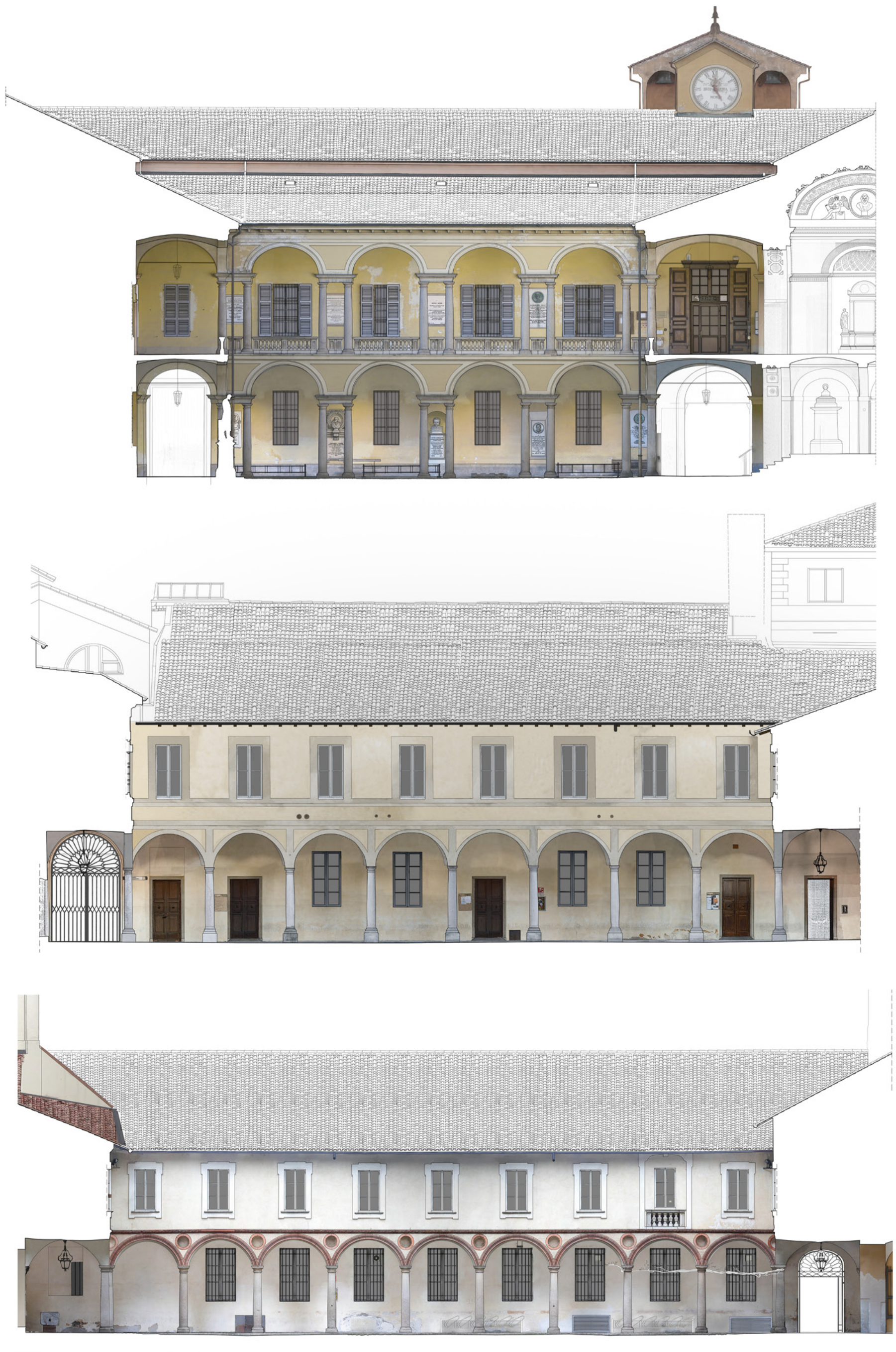
3.THE CASE STUDY OF PALAZZO CENTRALE FROM THE DOCUMENTATION TO THE INFORMATIVE SYSTEM

3.1 THE DOCUMENTATION AS THE FUNDAMENTAL TOOL FOR THE PROCESS OF KNOWLEDGE

Several qualities, including history, architectural features and social importance, contribute to the outstanding value of University of Pavia's Palazzo Centrale. One of them deserves special mention, and it is the particularly strong bond with the city of Pavia (Morandotti et al., 2019), which is immediately evident when looking at the Palace's footprint in the urban layout.
The plan development has been strongly influenced by pre-existent buildings, as it is the result of a number of merging and adaptive reuse processes that have been taking place until the 20s of the 19th Century.
The building's origin, though, is much farther in time: in fact, between 1485 and 1490 Ludovico il Moro authorized the use of a palace belonging to Azzone Visconti as the house of the Studiorum (Erba, 1972).
Starting from that moment the University grew in dimension by acquiring new spaces from adjacent buildings, according to its growing importance and prestige.
This historical development, which has been briefly summarized, is fundamental to understand how the complex acquired a valuable formal complexity and considerable extents - the Palace comprises 10 internal courtyards, to which Cortile Teresiano adds up; the latter one is open on one side and becomes the natural expansion of Piazza Leonardo Da Vinci.
Palazzo Centrale can be considered as a varied and complex result of stratifications that took place in several different epochs, and brought an exceptional value which is recognized both in the local and in the national context.
However, several conservation issues affect the Palace: it is observed, in particular, that extensive parts of the external plasters show severe degradation phenomena, such as gaps and inappropriate interventions; furthermore, most of the decorative elements are severely degraded.

Vitruvio
International journal of Architecture Technology and Sustainability
Volume 5 Is 1

Figure 4.
The three photoplanes highlight the variety of formal characteristics and archtectural styles that can be appreciated in Palazzo Centrale.
From the top, Cortile delle Statue (Courtyard of the Statues), Cortile dei Tassi (Courtyard of the Yews), Cortile Sforzesco (Courtyard of the Sforza).



These factors undermine the formal integrity of the complex, and make evident the need to put in place a planned action of conservation.

These are the premises of the documentation project, carried on according to a common purpose of the office of Technical Informative and Safety Area and the laboratories DAdaLab and PLAY of the University of Pavia, intending to define and implement an up-to-date knowing frame of the Palace. The aspects of the survey project have been determined considering the need to represent the object with all its formal, constructive and material characteristics, together with its conservation status and its relationships with the urban settings. At the same time, the project addresses the interoperability of information within an overarching point of view.

The phase of data acquisition required careful analysis and planning of the procedures in order to address the difficulties given by the extension and complexity of the Palace. This required to plan and organize the documentation activities dividing them into sectors to be surveyed. The integrated survey - range-based survey, carried on with laser scanner instruments, and image-based survey, with ground-level and UAV photographs – granted to acquire complete information on all the external surfaces and the monumental spaces, with equal attention dedicated to the roof system.

The survey data, heterogeneous for format and acquisition method, required a careful phase of organization and cataloging which has been fundamental for the methodology and the subsequent operation of reading, synthesis and interpretation.

The constitution of an archive, which could be easily looked through and enriched over time, required particular attention; one the one hand it was necessary in order to keep the database updated, following the creation of new data deriving from subsequent analyses; on the other hand, to avoid the natural process of fragmentation and dispersion of the information itself.

In the following phase, the dimensional data derived from the point cloud allowed to obtain detailed 2D drawings in a variety of architectural scales, while the photogrammetry allowed to create photo-planes of all the facades. These two outputs are the basis on which to operate for the following analysis on the object.

3.2 SEMANTIC ANALYSIS AS A KEY IN THE INTERPRETATION OF THE ARCHITECTURAL OBJECT

The definition of an appropriate methodology to create a database of Palazzo Centrale is strictly connected with the necessity of a management system able to efficiently represent all the dimensional and constructive features of the building.

Within this view, the semantic analysis of the fronts has been a fundamental step in the implementation of this approach.

In this phase, the architectural object is interpreted through morphological analysis and deconstruction, in which every single element is associated with the categories of a hierarchical system. In the case study, the definition of this system reaches the level of the architectural details.

The focal point of this process is an action that is priorly cognitive, and subsequently, practical, and consists in associating the geometry with a uniquely identified concept, that is part of a precise structure (De Luca, 2011).

This allows the management of the level of detail according to the specific objectives of the analysis: for example, the objectives of the analysis could be to define and distinguish the solids and voids, or the opaque and transparent surfaces; differently, it could be necessary to get down to the single decorative elements and defining their moldings.

Considering this issue, the breakdown operation has been carried out by steps to gradually reach the desired level of detail.

The first level allows identifying the main volumes that compose the building. In this phase it is necessary to define macroblocks that help to understand the relationships between the built elements.

In the second level, the main elements that form each building block are defined, by distinguishing horizontal elements, vertical elements, - continuous and discontinuous - and roofing.

This phase is fundamental to define the technical and constructive elements of each system and their relationships. These elements, which usually respond to a homogeneous construction technique, are to be considered as autonomous entities, to be further analyzed independently from the macroblock to

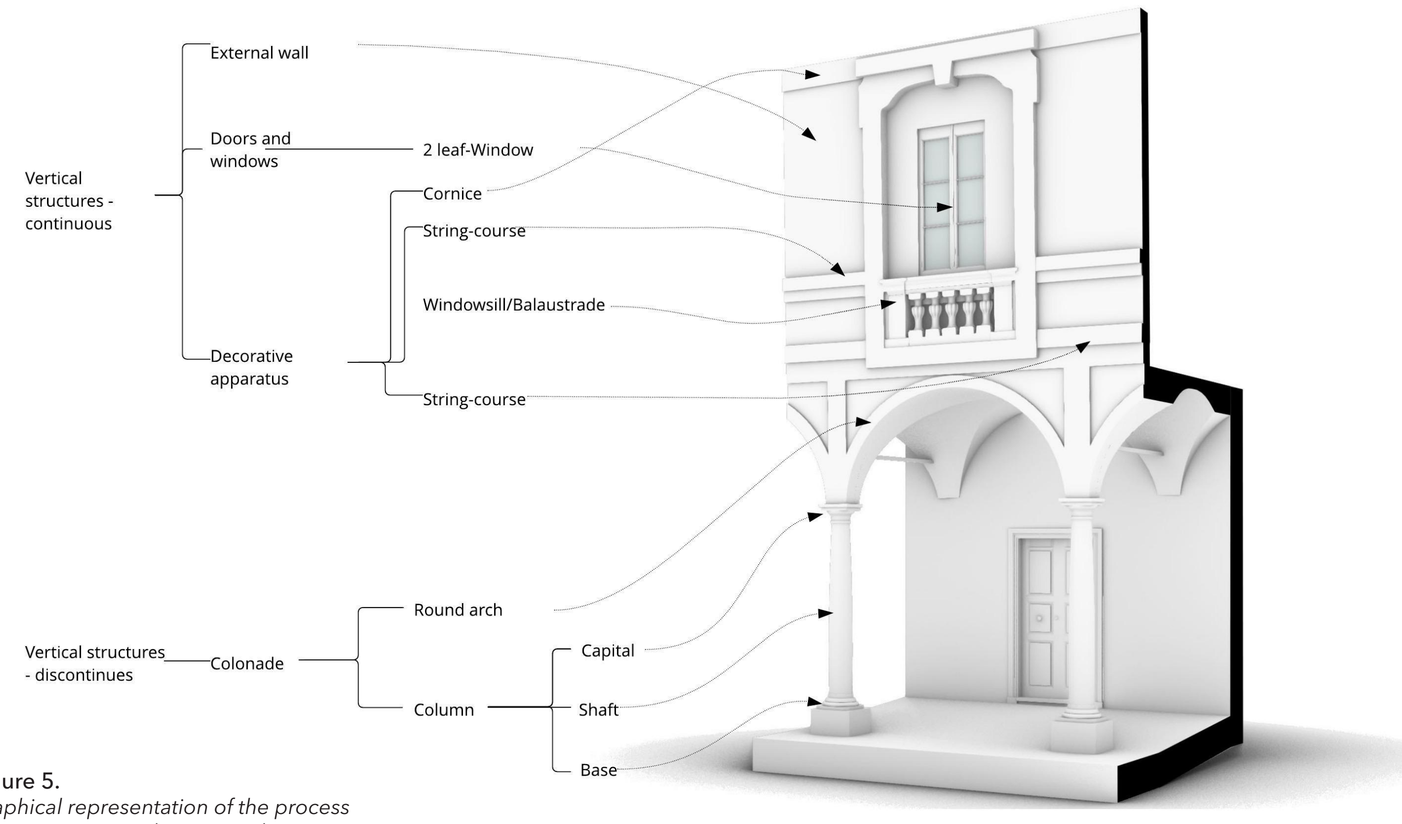


Figure 5.
Graphical representation of the process of construction analysis carried out on part of the façade of Cortile dei Tassi (Courtyard of the Yews).
The hierarchical structure reaches the level of the architectural detail.

which they belong.
The third level allows to identify the single architectural entities that compose the previously defined technological elements: these entities are, by way of example, walls, portals, doors, windows, columns.
Each element has the ability to be further separated into smaller sub-elements according to the specific analytic needs, and the breakdown can be deepened to reach the desired level of detail.
The definition of these elements translates into the identification of the boundary surfaces and modeling of geometries that define the single entities, according to the process of reverse modeling.
In other words, the creation of the three-dimensional model is the result of a critical reading of the architectural object that allows the transition from a set of undetermined information to a structured hierarchical system.
This action represented a critical step: the structure of the architectural elements underwent a process of decoding: after that, the system will return to be a significant element when it will be recomposed in the new virtual structure according to the ratio used in the process of breakdown (Picchio, 2017).

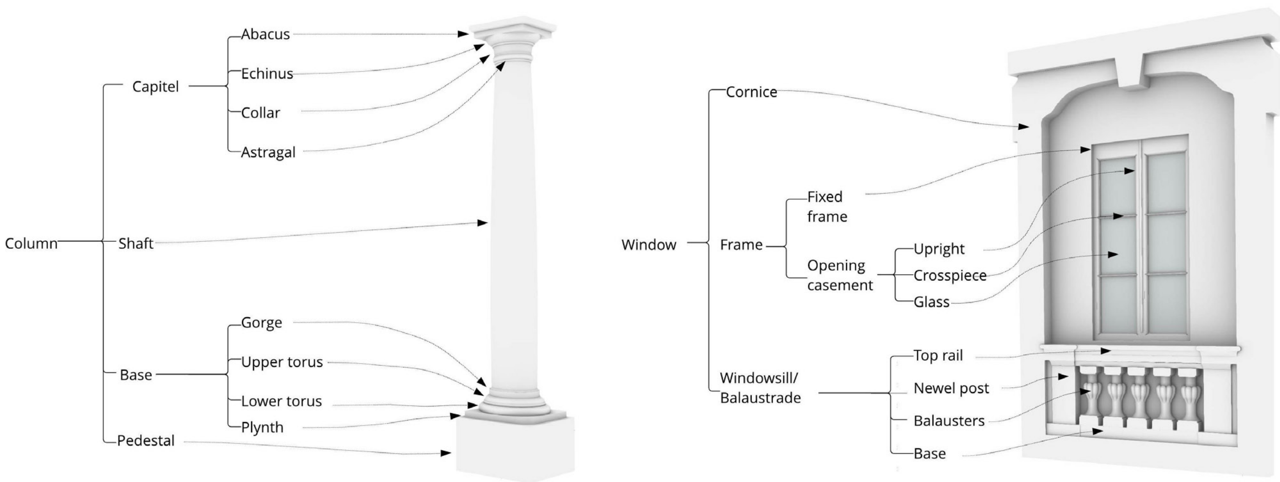


Figure 6.
Breakdown of architectural elements in minimal entities: on the right, one of the columns, on the left, one of the windows in Cortile dei Tassi (Courtyard of the Yews).

The peculiarity in the reconstruction of these entities is that the process is equally complex as the architectural object is. It is therefore imperative to verify the compliance with the dimension and measurements obtained from the survey. The act of drawing, once again, plays a fundamental role, since it lays the basis for the comprehension of geometries; ultimately, it makes it possible to obtain a reliable three-dimensional model that represents the characters of the real architectural with acceptable levels of approximation.
The model can be imported into the informative system where all the surveyed information can be extracted, and the knowledge can be deepened to the most detailed level that has been reached in the breakdown process.
The informative system allows to associate each identified element with a variety of census information that can be in different formats - by way of example, photographs, texts, high poly models that have not been included in the general model to preserve the lightness of use and maneuverability.
This allows responding to the issue of the standardization of the three-dimensional model and its ability to offer a comprehensive representation of the irregularities, the imperfections or the alterations due to the conservation status of the real object.
The informative system allows, in other words, to create a queriable model: in fact, it is possible not only to display the contained information for each element, but also to elaborate thematic charts, which graphically represent various possible interpretations of the collected data.
The so-structured data are an efficient support tool for the subsequent diagnosis, preliminary step for conservation and restoration actions.
The aforementioned disciplines require careful diagnosis analysis which can be developed thanks to the synthesis of multidisciplinary and diverse levels of knowledge. In turn, they produce additional data,

Vitruvio
International journal of Architecture Technology and Sustainability
Volume 5 Is 1

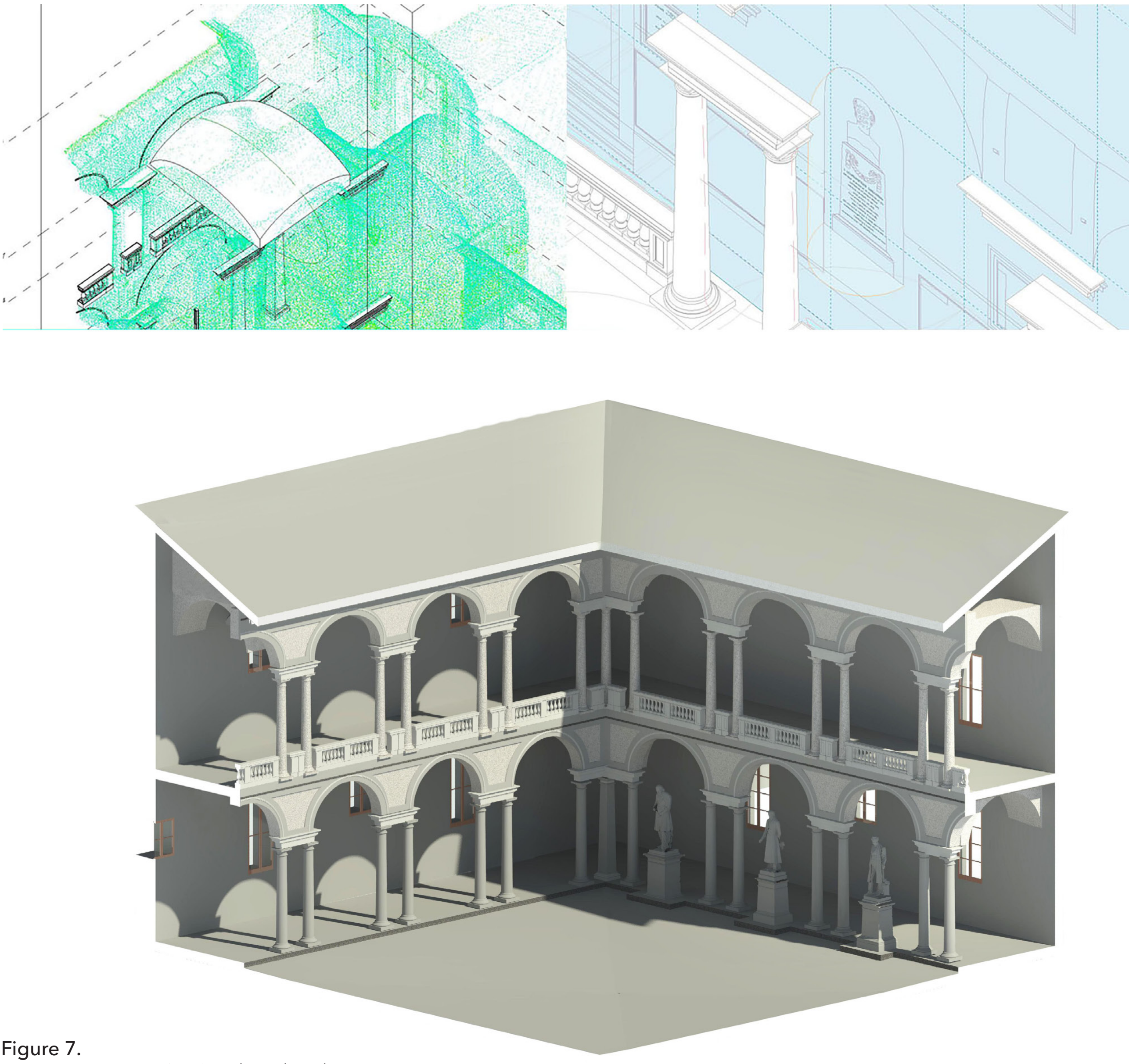


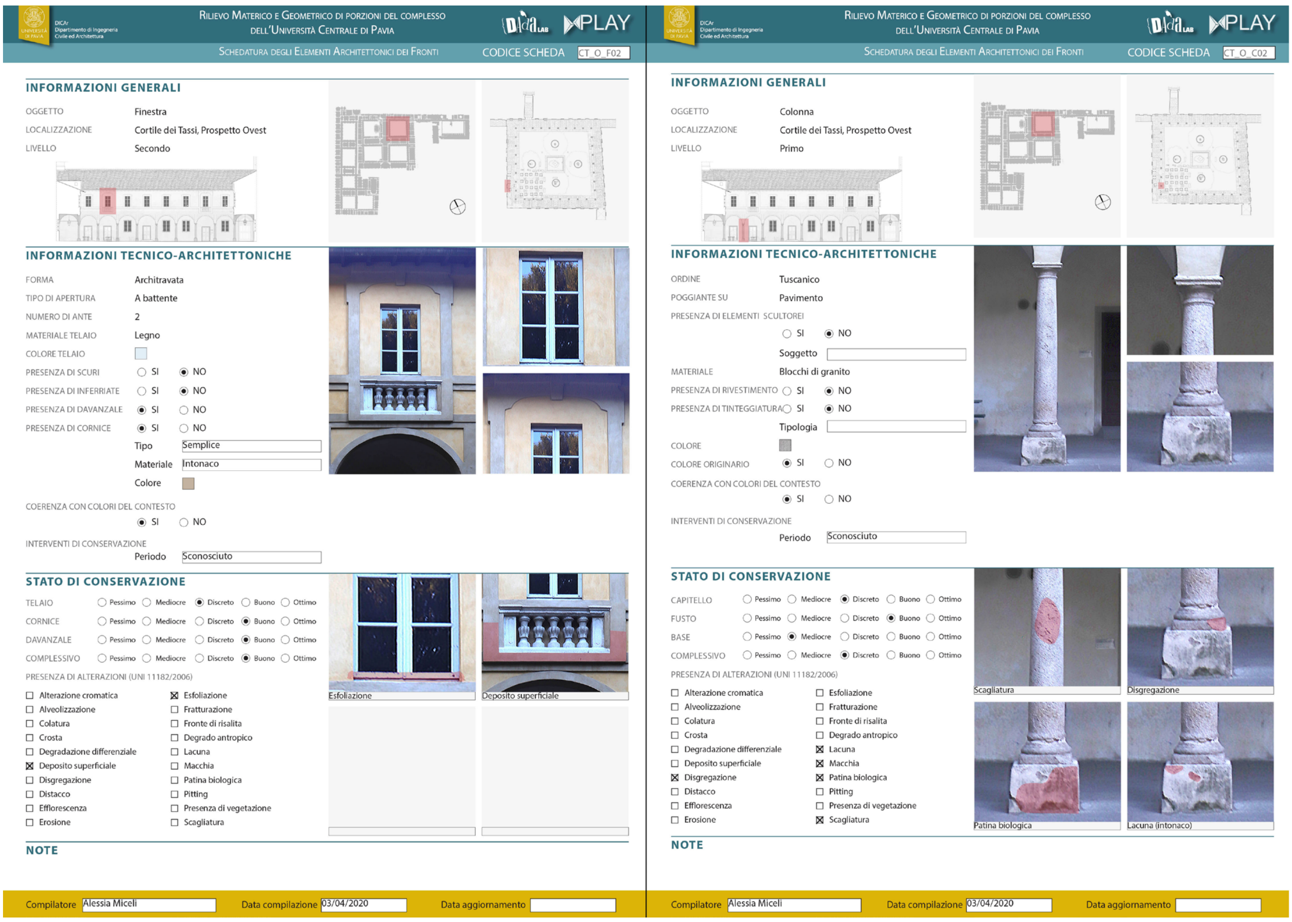
Figure 7.
Axonometric views (top) and rendered view (bottom) of the parametric 3D model (images by Anna Dell'Amico).

obtained from different techniques and protocols. Such information is often set on different support media without being mutually referenced, and therefore are hard to connect to each other - for example, we can mention the mapping of degradation phenomena on the building's different fronts: in this case, two-dimensional representations produce separate outputs resulting in the ability to synchronically read the information being compromised. Their link, as Messaoudi et al. stated, is based on a conceptual description of the building, without any reference to their mutual position (Messaoudi et al., 2017).

Considering that, integrating data deriving from these analyses into the informative system is once again an effective response; the potential is exploiting the potential of a unique tool, able to offer a comprehensive point of view on the current state of the object and, in addition, able to receive supplemental information in order to enrich the level of knowledge.

In fact, as well as we operate the semantic breakdown by identifying different regions in the model and associating each of them with specific descriptors

Figure 8.
Examples of census sheets filled up in regards to the architectural elements of one of Palazzo Centrale's courtyards.



- it is possible to replicate the same process with further analysis (relating, for example, to materials, construction techniques, conservation status and degradation phenomena) resulting in the creation of additional layers which the operators can value and compare simultaneously.

Organizing and integrating data and levels of knowledge in order to make them mutually connected and referenced can drastically improve the efficiency in the process of describing degradation phenomena and monitoring the conservation status.

Ultimately, the informative system can support the operators involved in the conservation actions and help them selecting feasible intervention strategies during the decision making process.

In the case study, the next level of analysis to be implemented in the informative system will regard the colorimetric analysis of the plastering. The results of this phase will constitute a layer of representation that will help define the chromatic characteristics of the plasters, highlighting their differences, discontinuities and decays.

The analysis will ultimately support the strategies aimed at their conservation or restoration, within an overarching view of management plan.

4. CONCLUSION AND FUTURE DEVELOPMENT

Recent experimentations carried on in the field of built heritage digitization lay the groundwork for rethinking the methodologies applied in the discipline of the architectural survey.

Digital instrumentation used in the survey of real objects (both laser scanners and photogrammetry) produces a massive amount of data that requires to be processed and interpreted; these processes, which are often time-consuming, are made up of both critical thinking (cataloging, discretization, analysis) and pragmatic actions (modeling, post-production).

This research pointed out relevant considerations on the aspects of these operations.

The first critical point is the necessity to discretize information, during the 2D representation and, most of all, during the creation of the three-dimensional model.

The second critical point is brought about by the necessity of controlling the model reliability - or, in other words, how much it complies with the imperfections and heterogeneity of the real object.

Within this view it is necessary to tackle two different needs:

on the one hand the necessity of high reliability of the representation, which derives from the consolidated principles of the architectural survey and is ensured by the modern instrumentation available;

on the other hand, an equally necessary manoeuvrability and manageability of the model, to be ensured in terms of standardization, meaning rapidity in the modeling action, and terms of lightness of the model.

The latter one is particularly marked when we deal with artifacts whose uniqueness results in their “primary value and project constraint” (Bianchini, 2016), and it is even more evident in the case of particularly vast and varied monumental complexes, as the case study is.

In response to these issues, a well-reasoned reading of the geometrical elements that constitute the architecture allows to identify the repeatable entities that will be elected as the fundamental elements of the model.

The semantic structure of the 3D model becomes the basis of an archival system that is open, updatable, and able to connect the information obtained from the survey with the ones deriving from all the subsequent analyses. The enrichment is, therefore, possible in terms of new categories and classes as well as new instances: the informative system represents at the same time a database and support for visualizing and interacting with collected information (Parrinello et al., 2017).

Moreover, the ability to structure information according to a chronological ratio makes the database sensitive to the temporal dimension and not only a mere picture restricted to the census time (Bertocci et al., 2014)

These considerations lay the foundation for upcoming research developments that will involve and enrich the informative system with new levels of knowledge, starting from the colorimetric analysis of the fronts.

These procedures make it possible to set up structured

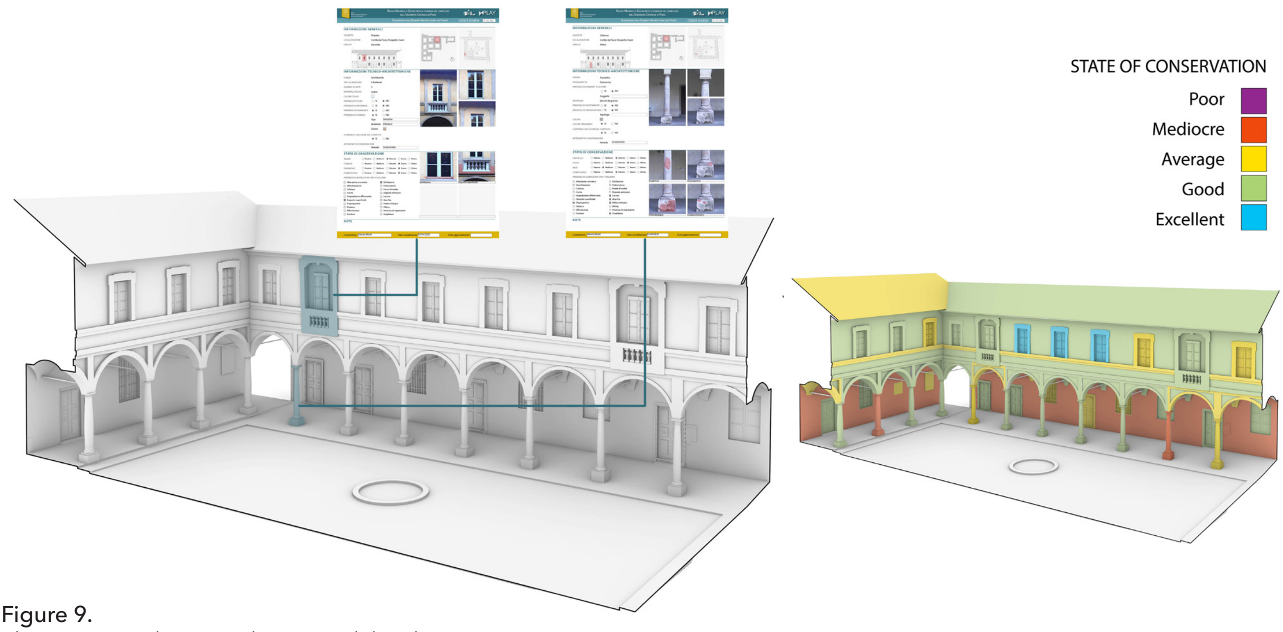


Figure 9.
The integration between the 3D model and the census sheets creates an informative support, queriable and enrichable, able to display thematic maps.

plans for the monitoring and maintenance of the fronts, with the objective of long-term management of the built heritage.

Within a broader view, the objective of the research is the creation of an informative system that comprises the architectural heritage of the University of Pavia, through the application of the methods and protocols here exposed to the entire asset of buildings belonging to the Lombard institution.

This action would allow to structure maintenance and conservation plans while considering the single building's issues within a holistic point of view: controlling and defining priorities in the interventions means to implement the principles of a well-reasoned approach to the conservation issues and efficient use of resources (Della Torre, 2010).

Further possibilities regard the creation of collaborative tools that exploit the interaction between augmented reality environments and 3D models to support the visualization, monitoring and real-time comparison of the building's conservation status; this interaction would certainly enhance the effectiveness and the level of utilization of the tool.

Ultimately, the chance to exploit the use of the 3D model as a tool for diffusion and valorization for the public is to be explored: cultural heritage is undergoing a process of dematerialization of the fruition: informative systems present the potential to reproducing real spaces in environments to be experienced virtually.

The creation, by way of example, of virtual museums or interactive spaces for knowledge and learning appears to be strongly motivated by the importance of the monumental complex of Palazzo Centrale in the city of Pavia.

REFERENCES

Attenni, M. (2019) Informative Models for Architectural Heritage. Heritage, 2, 2067-2089.
DOI: 10.3390/heritage2030125

Bertocci, S., Bua, S., Parrinello, S., Picchio, F. (2014) Montepulciano 3D: virtual models for urban planning and development of the urban environment. Disegnarecon, 7(13), 1-20.
DOI: 10.6092/issn.1828-5961/4152

Bianchini, C., Inglese, C., Ippolito, A. (2016) The role of BIM (Building Information Modeling) for representation and managing of built and historic artifacts. Disegnarecon, 9(16), 10.1-10.9.

De Luca, L. (2011) Towards the semantic characterization of digital representations of architectural artifacts: programmatic lines of research. Disegnarecon, 4, 99-106.
DOI: 10.6092/issn.1828-5961/2574

Della Torre, S. (2010) Conservazione programmata: i risvolti economici di un cambio di paradigma. Il Capitale culturale – Studies on value of cultural heritage, 1, 47-55.
DOI: 10.13138/2039-2362/30.

Dore, C., Murphy, M. (2012) Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites. 18th International Conference on Virtual Systems and Multimedia: "Virtual Systems in the Information Society", Milano 2-5 September.

Erba, L. (1976) Guida storico-artistica dell'Università di Pavia. Fusi Editore, Pavia.

Giannattasio C., Papa L.M., D'Agostino P., D'Auria S. (2020) The BIM Model for Existing Building Heritage: From the Geometric Data Acquisition to the Information Management. In: Agustín-Hernández L., Vallespín Muniesa A., Fernández-Morales A. (eds) Graphical Heritage. EGA 2020. Springer Series in Design and Innovation, vol 5. Springer, Cham.
DOI: https://doi.org/10.1007/978-3-030-47979-4_28

Messaoudi, T., Véron, P., Halin, G., De Luca, L. (2017) An ontological model for the reality-based 3d annotation of heritage building conservation state. Journal of cultural heritage, 29, 100-112.
DOI: 10.1016/j.culher.2017.05.017

Parrinello, S., Miatton, C. (2017) Descriptive models for the management of the maintenance work on the façade of the Basilica of San Michele in Pavia. 3D Modeling & BIM Progettazione, design, proposte per la ricostruzione. Roma. 19-20 April.

Moles, A. A. (1972) Teoria informazionale dello schema. Versus, 2, 29-37.

Morandotti, M., Parrinello, S., Picchio, F., Becherini, P., De Marco, R., Dell'Amico, A., Doria, E., Galasso, F., Malusardi, C. (2019) L'Università di Pavia. I cortili e gli ambienti monumentali. Un progetto di documentazione digitale e sviluppo di sistemi di gestione per la manutenzione programmata. VII Convegno Internazionale sulla documentazione, conservazione, recupero del patrimonio architettonico e sulla tutela paesaggistica. ReUSO2019, Matera, 23-26 October.

Niglio, O. (2017) Memory and Technology. VITRUVIO – International Journal of Architectural Technology and Sustainability, 2 (2), viii.
DOI: 10.4995/vitruvio-ijats.2017.9008

Oreni, D., Brumana, R., Georgopoulos, A., Cuca, B. (2013) HBIM for Conservation and Management of Built Heritage: Towards a Library of Vaults and Wooden Bean Floors. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., II-5/W1, 215–221.
DOI: https://doi.org/10.5194/isprsannals-II-5-W1-215-2013

Paris, L., Wahbeh, W. (2016) Survey and representation of the parametric geometries in HBIM. Disegnarecon, 9(16), 12.1-12.9.

Parrinello, S., Gómez-Blanco Pontes, A., Picchio, F., Rodriguez Moreno, C., Rivas López, E. (2019) An integrated system for documentation, analysis and management of the architectural heritage: the general and the parts of the Generalife Palace. EGA Revista de Expression Grafica Arquitectonica 24(35) 140-151. DOI: 10.4995/ega.2019.9527

Parrinello, S., Picchio, F., Becherini, P., De Marco, R. (2017) Methodological evolution and representative protocols for charterhouses complex. 39° Convegno internazionale dei docenti delle discipline della rappresentazione, XIV Congresso Unione Italiana Per Il Disegno (UID). Territori e frontiere della rappresentazione, Napoli, 14-16 September.

Parrinello, S., Picchio, F., De Marco, R., Dell'Amico, A. (2020) Prometheus. Protocols for information models libraries tested on heritage of Upper Kama sites. II Simposio UID di internazionalizzazione della ricerca. Patrimoni culturali, Architettura, Paesaggio e Design tra ricerca e sperimentazione didattica, Matera, 22 October.

Parrinello, S., Picchio, F., Dell'Amico, A., De Marco, R. (2020) A Digital Model for the Management of Museum of Alhambra Complex: The Digital Documentation of Mezquita Bath itale dei bagni della Mezquita. II Simposio UID di internazionalizzazione della ricerca. Patrimoni culturali, Architettura, Paesaggio e Design tra ricerca e sperimentazione didattica, Matera, 22 October.

Picchio, F. (2016) Configuration of virtual landscape of historical centre of Pavia. The Drawing for the abstraction of urban complexity. 38° Convegno internazionale dei docenti delle discipline della rappresentazione, XIII Congresso Unione Italiana Per Il Disegno (UID). Le ragioni del disegno, Firenze, 15-17 September.

Picchio, F. (2017) La catalogación de los elementos arquitectónicos. In: Parrinello, S., Gómez-Blanco, A., Picchio, F., El palacio del Generalife. Del levantamiento digital al proyecto de gestion. Pavia University Press, Pavia.

Pocobelli, D.P., Boehm, J., Bryan, P., Still, J,m Grau-Bovè, J. (2018) BIM for Heritage Science: a Review. Heritage Science 6, 30. DOI:https://doi.org/10.1186/s40494-018-0191-4

Quattrini, R., Clini, P., Nespeca, R., Ruggeri, L. (2016) Measurement and Historical Information Building: challenges and opportunities in the representation of semantically structured 3D content. Disegnarecon, 9, 14.1-14.11.

Stefani, C., Brunetaud, X., Janvier-Badosa, S., Beck, K., De Luca, L., Al-Mukhtar, M. (2012) 3D Information System for the Digital Documentation and the Monitoring of Stone Alteration. In: Ioannides M., Fritsch D., Leissner J., Davies R., Remondino F., Caffo R. (eds) Progress in Cultural Heritage Preservation. EuroMed 2012. Lecture Notes in Computer Science. Vol. 7616. Springer, Berlin & Heidelberg

Yang, X., Lu, Y., Murtiyoso A., Koehl, M., Grussenmeyer, P. (2019) HBIM Modeling from the Surface Mesh and its Extended Capability of Knowledge Representation. International Journal of Geo-Information, 8(301), 1-17.
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