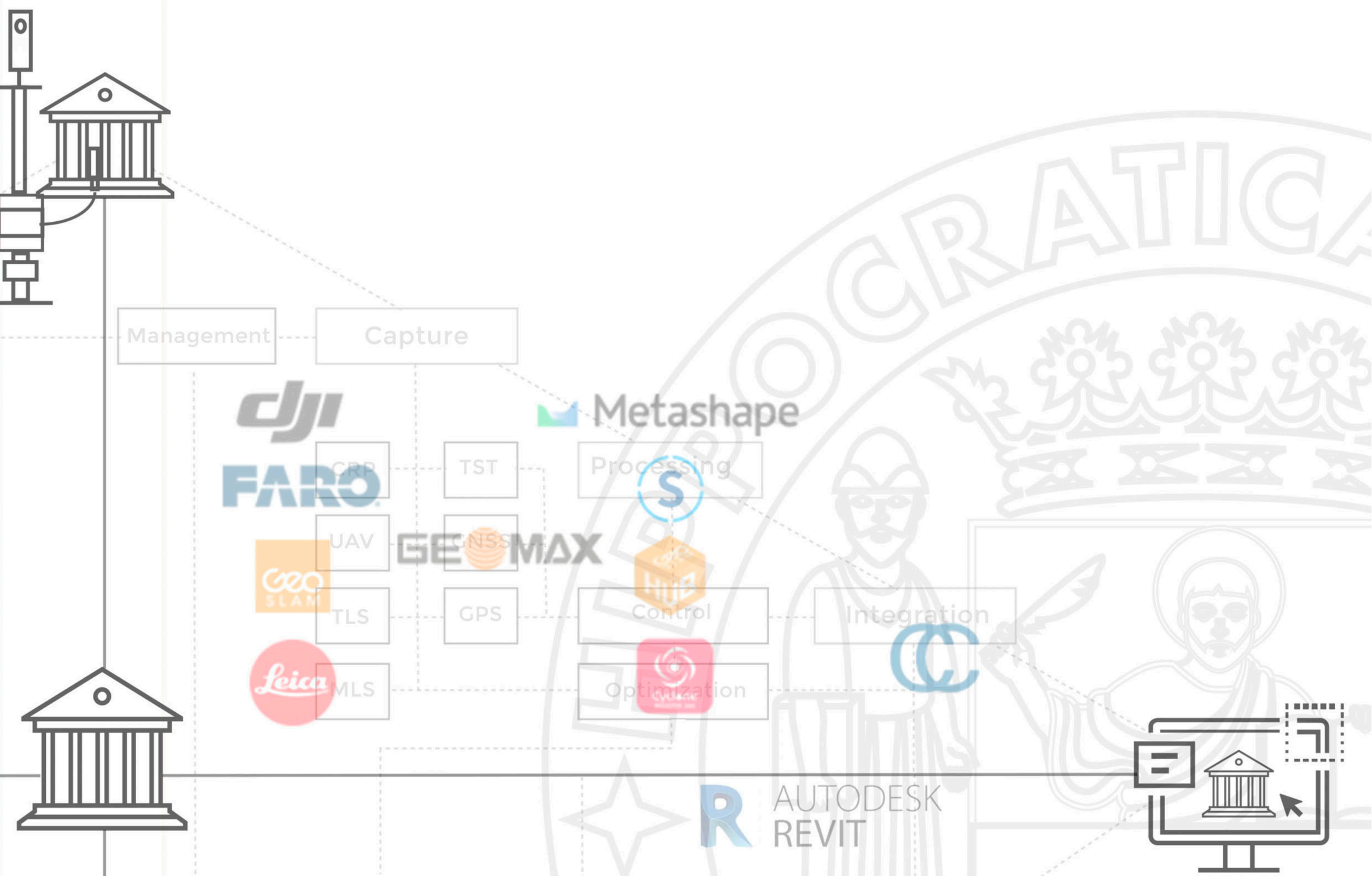
University of Salerno
Department of Civil Engineering

PhD Course in Risk and Sustainability
in Civil, Architectural and
Environmental Engineering Systems

XXXIII Cycle (2018/2020)



Carla Ferreyra

A proposal for the expanded fruition of Cultural Heritage Sites:

CAME, a methodology for their digitization

Coordinator
Fernando Fraternali

Tutor
Salvatore Barba

Co-tutor
Mona Hess

This thesis will be presented for the recognition of *Doctor Europaeus*.
It has been conducted within the framework of the PhD course of the Department of Civil Engineering of the University of Salerno in Italy under an international cooperation agreement with the Chair of Digital Technologies in Heritage Conservation of the University of Bamberg in Germany and the Faculty of Architecture of the Tshwane University of Technology in South Africa.

March 31st, 2021.

I have not been everywhere… but it is on my list!

Susan Sontag

FOREWORD BY JACQUES LAUBSCHER

Long after the extinction of a community, artefacts remain as a testament to its existence. Although valid for all forms of life, the artefacts left behind by humankind are noteworthy for architects and engineers.

An artefact (the tangible) represents an intricate knowledge system (the intangible) acquired over different ages by communities through their interaction with the environment. This indigenous knowledge system is often lost to the generation that is unearthing it. An investigation is a process of discovery allowing scientific insight into past civilizations using current thinking and technology.

The PhD thesis by Ms Carla Ferreyra makes a critical knowledge contribution through three case studies that vary in size and scale. The applied research methodology uses different digital surveying and data processing techniques to document the built heritage as a cultural resource.

The first case study is Villa Rufolo in Ravello, Italy, and it is the main focus of the research. The building scale of Villa Rufolo has a complex series of layers that were deposited over time. It is investigated by integrating the SLAM, TLS, UAV & GNSS digital surveying methods. The measuring scale changes in the second case study when the SLAM based technique is used to collect data in the gardens and landscapes of Ebracher Hof in Mainstockheim and Ebracher Hof in Oberschwappach, Germany. On a larger territorial or regional scale, the third case study uses the CAME methodology to investigate the Moxomatsi village in the Mpumalanga province of South Africa.

The thesis uses a multi-disciplinary approach to identify, study and document the built artefacts of the three case studies. Different methods to digitize the artefact display the potential of making information on forgotten civilizations available to larger audiences. The thesis is structured and legible, while the inclusion of 13 videos makes it possible for the reader to undertake digital site visits to the case studies. Through her research, Ms Ferreyra illustrates how historical built artefacts can be recorded and protected for current and future generations through advanced digital tools and technologies.

On a personal note, I first met Carla at the beginning of 2016 when Prof. Dr. Salvatore Barba approached me to act as a co-supervisor for her Master's thesis. It was an honour to work with both of them, and it was an important milestone on the fruitful journey with the "Laboratorio Modelli" at UNISA.

Over the past five years, I have witnessed the academic and professional growth of Carla. During this time, she developed from a young curious architectural graduate from Argentina to a fully-fledged engineering scientist in photogrammetry and digital surveying who conducts interdisciplinary research that is recognized worldwide.

Jacques Laubscher
Head of Department Architecture and Industrial Design
Tshwane University of Technology, Pretoria

FOREWORD BY SECONDO AMALFITANO

An architecture lives according to the story it manages to tell. Nearly every time the story of these monuments is limited to representing and exalting two topical moments: the origin and the actuality.

Villa Rufolo until 2007 narrated to the world a rather simple and stereotyped story. Its birth is linked to the life of the family that gave it its name, the Rufolo family who, having become rich through trade in the Mediterranean, wanted to symbolize their magnificence and wealth through the impressiveness of a sumptuous palace full of Arabian designs. Its actuality is the result of the work and mastery of two important names of the nineteenth century, Nevile Reid, a cultured and rich Scot, and Michele Ruggiero, architect-archaeologist who linked his name to the discovery of old Pompeii.

From the day I took office as Director of this wonderful monument, I had one overriding thought: to rediscover and reconstruct its true history, to retrace the thousand years of its existence.

I started with documentary research, made of books and parchments, but I soon realized that there were too many gaps, not to mention the most recent studies that in some cases were misleading and/or distant from reality. I soon moved on to direct excavation, at first almost by chance or, in any case, not aimed at research. It seemed that history was limited to only three clearly distinguishable pages: the first, of the construction period, signed by anonymous but very skilled workers; the second, that of the restoration, attributable to the Reid-Ruggiero duo, written in the language of logic, wisdom, mastery, competence, almost "obvious predictability"; the third, the least faded of the three, the one of contemporaneity, impressed with the ink of the bizarre, casual, incoherent, chaotic.

That historical reconstruction was not at all exciting, not pretty to rewrite or even to re-listen.

Fortunately for Ravello and for Villa Rufolo, but also for me, a chance encounter arrived, the one that was neither planned nor pursued, the one determined by destiny. But, as is well known, it is important that fate also takes responsibility for determining the future: two students from the Department of Civil Engineering of the University of Salerno, two students interested in the traces of Louis Kahn's presence in Ravello, crossed the gate of Villa Rufolo. Their professor, Salvatore Barba, asked me to help the students in the development of their thesis. Sometimes in life it happens that good thing happen faster than bad things; I pointed out to the two students that perhaps the topic chosen was 'narrow' for two dissertations and I suggested that one of them could be dedicated to Villa Rufolo.

One of the two, Lucia Fernandez, decided to work on this collection of news to rewrite a history. A master's thesis arrived and later also the publication of the volume that not by chance was titled: "Villa Rufolo, una storia che dura da mille anni".

From that student and from that chance, a real research program started, which found its last synthesis in Carla Ferreyra's work.

The intent was to make the monument itself reveal its history. The new technologies would allow us to use the stones as a pen and the mortar as an ink to tell a story made up not only of construction techniques, but also of periods of decadence and wealth.

The tool of BIM (Building Information Modeling), born to better manage the design and construction of the "new", the HBIM (Heritage Building Information Modeling) becomes a tool for the management of the "built", but also for the knowledge of its architectural and structural evolutions. These, if dated and contextualized, become a valid element of reconstruction of historical, social, and economic events.

In the case of Villa Rufolo, the study and interpretation of the point cloud has allowed us not only to discover events that had escaped or had never been reported, but also to place, with scientific rigor, circumstances that were previously known in an approximate or incorrect way.

Carla Ferreyra's work is the synthesis of a series of crossovers between technology, instruments, and documentation; together they make it possible today to have an instrument that is complex and agile at the same time, one that will make it possible to collect all of the thousand years of life at Villa Rufolo with all of the details that make the story less fanciful and much more captivating and precise.

To stop only at this would be a serious mistake, however, because the study carried out so far also offers support for the ordinary and daily management of the cultural asset. The maintenance of a monument has always been a difficult test for workers and technicians; I have often found myself faced with "surprises" that have complicated interventions. The most frequent thing that happens, for example, is to come across unknown stratigraphist of other interventions, especially in those monuments that have had a non-continuous life but interspersed with periods of stagnation and abandonment.

Today, the availability of surveys and studies in HBIM environment, which allow to connect the different levels of information in a three-dimensional view, allows those who have the responsibility of the monument to plan and design the maintenance interventions with more rigor and precision.

In closing, it must be underlined that the use of an integrated methodology has still unknown boundaries. I would like to recall that in the case of Villa Rufolo, the documentation produced has made it possible to set up events of mapped and hologrammatic projections that have enhanced the emotional effects on viewers: the monument, its facades, its arabesques have come alive with effects of exceptional realism, telling their story to visitors, and succeeding in deeply moving them. Another use of these studies, unfortunately only hypothesized and not yet realized, is the three-dimensional printing of the various rooms of the monument to make possible for the visually impaired the tactile visit of this palace that counted "more rooms than days of the year".

Secondo Amalfitano
Former Mayor of Ravello
and Director of Villa Rufolo

ABSTRACT

Architectural and landscape heritage can be defined as the tangible - and intangible - memory of a community's culture. It is an immense resource, but at the same time, yet enormously fragile and, unfortunately, essentially non-renewable. Its recognition as such implies a permanent action aimed at its knowledge and conservation, in order to ensure its correct transmission to future generations.

The research project, in an attempt to respond to these needs, has explored innovative methodologies for the management and analysis of risks, vulnerability of cultural heritage and social impact, topics absolutely aligned with the research areas of the Department of Civil Engineering of the University of Salerno and the PhD Course in *Risk and Sustainability in Civil, Architectural and Environmental Engineering Systems.* Thereby, I have had the opportunity to highlight the role and the current impact of digital technologies for the knowledge and protection of cultural heritage. In the first chapter I will therefore focus on defining and assessing the importance of cultural heritage as a sustainable resource for society and how to protect it, considering its possible risks, from the more engineering ones to oblivion and/or loss of cultural memory.

Scientific and technological advances that promote strategies to protect cultural heritage are the order of the day: digitization, modeling, visualization, and the use of immersive systems have acquired unprecedented weight. The second chapter will highlight the new horizons that allow the incorporation of very different perspectives on heritage, involving increasingly specialized disciplines, with their own languages and algorithms. It will present the most contemporary international initiatives and strategies to improve qualitatively and quantitatively, through the tools offered by digital technologies, the possibilities of approaching the knowledge of cultural heritage by promoting new systems to interpret and conserve it.

The methodology, which contemplates the analysis, digitization, and fruition of heritage, has been designed and applied in three case studies potentially recognizable by UNESCO as World Heritage Sites. Based on documentary research and the application of integrated digital survey and data processing techniques, actions have been developed to meet the increasing needs of society in terms of survey, recovery, and conservation.

The cases analyzed do not follow a chronological order, but are presented in an order of scale, progressively moving away from the object. The first case study, on an architectural scale, focuses on an emblematic example of medieval Italy; the second case study, on a landscape scale, deals with the gardens and landscapes of Baroque Germany; finally, the last case study, this time on a territorial scale, focuses on one of the most extraordinary archaeological testimonies of pre-colonial South Africa.

For the main case study, focused on a symbolic historical architecture of southern Italy, Villa Rufolo in Ravello, an integrated survey approach is presented in support of HBIM (Historic Building Information Modeling) in the framework of a project funded by the University of Salerno in collaboration with the then Management of Villa Rufolo. The project was born from the need to deepen the state of knowledge of the object of study and from the idea of how to digitize it, with the first results merged in the monograph *Villa Rufolo. Una scoperta che dura da mille anni*. The workflow has always been accompanied by the use and integration of advanced digital survey techniques: according to needs, objectives, and complexity characteristics, implementing different approaches and techniques, as presented in the contribution in the volume *A pipeline for the integration of 3D data on aero photogrammetric frameworks. The case study of Villa Rufolo*. Passive sensors, such as UAV (Unmanned Aerial Vehicle) photogrammetry with GNSS (Global Navigation Satellite System) support, and active sensors, such as TLS (Terrestrial Laser Scanning) and MLS (Mobile Laser Scanning), have been integrated and used as

a basis for a further strategic experimentation of a multidimensional HBIM modeling (submitted to the scientific journal “disegnarecon” in *BIM Reverse modelling process for the documentation in Villa Rufolo in Ravello*). According to, a reverse engineering process, starting from the point cloud, the elements of the case study have been modeled, following an adequate definition of priorities and a classification of development levels, proceeding to an original deepening of the concept of accuracy and considering a realistic visualization towards an “as-built” documentation; the technique *Image-based Elaborations to improve the HBIM Level of Development* has been accepted for publication in “3D Modeling & BIM”.

The second case study, at landscape scale, is located in Germany and was approached in conjunction with the concluding phase of my PhD. Cistercian landscapes have represented an interesting scenario on which to test the latest updates of the MLS methodology, generating an accurate infographic that has been explored in the project Cisterscapes - Cistercian Landscapes Connecting Europe; the results have been merged in the proposal *Recording and comparing garden architecture, value of slam-based recording for research on cultural landscapes in connection with heritage conservation* submitted to the CIPA ICOMOS Heritage Documentation. In addition, this stay abroad has served to carry out more tests on this new instrumentation and to know the best practices of the instrument, deepening in the SLAM (Simultaneous Localization And Mapping) technique characterized by the speed of data acquisition. This experience laid the foundations for the publication *A SLAM integrated approach for Digital Heritage Documentation* in Springer Digital Library.

The third and last case study, on a territorial scale, summarizes the activities carried out during the first two years of my PhD, aligned with my background, in the framework of a project funded by the Italian Ministry of Foreign Affairs and International Cooperation. In particular, I had the opportunity to experiment with drone surveys as a starting point for architectural design. Some of the results have already been published in *Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina* (IX Convención de Agrimensura), *SSIMM: Italy-South Africa joint Research Project: the architectural response* (II Simposio dell’Unione Italiana per il Disegno - Internazionalizzazione della Ricerca) and *Documentation and enhancement of the cultural landscape of South Africa* (D-SITE, Drones - Systems of Information on Cultural Heritage).

The objective was to digitize all the information acquired from the different case studies, analyze it, order it, and catalog it in digital data repositories, to facilitate collaboration and management in an interdisciplinary environment, and thus facilitate tasks and optimize processes.

Digital resources, in fact, not only facilitate and improve the scientific-technological processes traditionally used for heritage protection, but also constantly change the way of understanding, perceiving, and transmitting heritage, offering a new horizon of decisional strategies towards an increasingly sustainable conservation.

ABSTRACT

Il patrimonio, architettonico e paesaggistico, può essere definito come la memoria materiale - e immateriale - della cultura di un popolo. È una risorsa immensa, ma allo stesso tempo, enormemente fragile e, purtroppo, essenzialmente non rinnovabile. Il suo riconoscimento come tale implica un'azione continua volta alla sua conoscenza e conservazione, per assicurare la sua adeguata trasmissione alle generazioni future.

Il progetto di ricerca, nel tentativo di voler rispondere a queste esigenze, ha sperimentato metodologie innovative per la gestione e l'analisi dei rischi, della vulnerabilità del patrimonio culturale e dell'impatto sociale, argomenti assolutamente in linea con le aree di ricerca del Dipartimento di Ingegneria Civile dell'Università degli Studi di Salerno e del Corso di Dottorato in *Rischio e sostenibilità nei sistemi dell'ingegneria civile, edile ed ambientale*. Ho così avuto l'occasione di mettere in evidenza l'attuale ruolo e l'impatto delle tecnologie digitali per la conoscenza e la protezione del patrimonio culturale. Nel primo capitolo mi concentrerò, quindi, nel definire e valutare l'importanza dei beni culturali come risorsa sostenibile per la società e su come proteggerli, considerandone gli eventuali rischi, da quelli più ingegneristici fino all'oblio e/o alla perdita della memoria culturale.

I progressi scientifici e tecnologici che promuovono le strategie di protezione del patrimonio culturale sono all'ordine del giorno: digitalizzazione, modellazione, visualizzazione e l'uso dei sistemi immersivi, hanno acquisito un peso senza precedenti. Nel secondo capitolo si metteranno in evidenzia i nuovi orizzonti che permettono di incorporare prospettive molto diverse sul patrimonio, coinvolgendo discipline sempre più specializzate, con i propri linguaggi e algoritmi. Si presenteranno le più contemporanee iniziative e strategie internazionali per migliorare qualitativamente e quantitativamente, attraverso gli strumenti offerti dalle tecnologie digitali, le possibilità di approccio alla conoscenza del patrimonio culturale promuovendone nuovi sistemi per interpretarlo e conservarlo.

La metodologia, che contempla l'analisi, la digitalizzazione e la fruizione del patrimonio, è stata disegnata e applicata su tre casi studio riconoscibili come patrimonio dell'umanità UNESCO. Sulla base di una ricerca documentaria e l'applicazione di tecniche integrate di rilievo digitale ed elaborazione dati, sono state sviluppate azioni per rispondere alle esigenze sempre più frequenti della società in termini di rilievo, recupero e conservazione.

I casi studi analizzati non seguono un ordine cronologico ma piuttosto sono presentati secondo un ordine di scala, allontanandoci progressivamente dal manufatto. Il primo caso studio, a scala architettonica, si focalizza su un emblematico esempio dell'Italia medievale; il secondo caso studio, a scala paesaggistica, è relativo ai giardini e paesaggi della Germania barocca; infine, l'ultimo caso studio, questa volta a scala territoriale, ha trattato una delle più straordinarie testimonianze archeologiche del Sudafrica precoloniale.

Per il caso studio principale, un'architettura storica simbolica del Sud d'Italia, Villa Rufolo a Ravello, si presenta un approccio basato su rilievi integrati come supporto al HBIM (Historic Building Information Modeling) nell'ambito di un progetto finanziato dell'Università di Salerno in collaborazione con l'allora Direzione di Villa Rufolo. Progetto che era nato proprio a partire dalla necessita di approfondire lo stato di conoscenze sul manufatto e dall'idea di come poterlo digitalizzare, coi primi risultati confluiti nella monografia *Villa Rufolo. Una scoperta che dura da mille anni*. Il flusso di lavoro è sempre accompagnato dall'uso e integrazione di tecniche avanzate di rilievo digitale: secondo le necessità, gli obiettivi e le caratteristiche di complessità, sono stati implementati diversi approcci e tecniche, così come confluiti nel contributo in volume *A pipeline for the integration of 3D data on aero photogrammetric frameworks. The case study of Villa Rufolo*. Sensori passivi, come la fotogrammetria UAV con supporto GNSS, e sensori attivi, come

il laser scanner statico TLS e dinamico MLS, sono stati integrati e utilizzati come base per una posteriore sperimentazione strategica di modellazioni HBIM multidimensionale (presentati alla rivista scientifica “disegnarecon” in *BIM Reverse modelling process for the documentation in Villa Rufolo in Ravello*). Quindi, seguendo un processo di ingegneria inversa, a partire dalla nuvola di punti, sono stati modellati gli elementi del caso studio, seguendo un’opportuna definizione delle priorità e una classificazione dei livelli di sviluppo, procedendo a un’originale approfondimento sul concetto di accuratezza e relativamente alla visualizzazione realistica verso una vera e propria documentazione “as-built”; la tecnica *Image-based Elaborations to improve the HBIM Level of Development* è stata accetta per la pubblicazione in “3D Modeling & BIM”.

Il secondo caso studio, a scala paesaggistica, è situato in Germania ed è stato trattato in concomitanza con la fase più conclusiva del mio percorso di dottorato. I paesaggi cisterciensi hanno rappresentato un interessante episodio su cui per testare gli ultimissimi aggiornamenti della metodologia MLS, generando un’accurata infografica da esplorare nel progetto Cisterscapes - Cistercian Landscapes Connecting Europe; i risultati sono poi confluiti nella proposta *Recording and comparing garden architecture, value of slam-based recording for research on cultural landscapes in connection with heritage conservation* presentata all’International Committee of Architectural Photogrammetry CIPA ICOMOS Heritage Documentation. Inoltre, questo soggiorno all’estero è valso per portare a termine ulteriori test su questa nuova strumentazione e per accertare le migliori pratiche dello strumento, approfondendo la tecnica dello SLAM caratterizzata per la rapida acquisizione dei dati. Quest’esperienza ha gettato le basi per la pubblicazione *A SLAM integrated approach for Digital Heritage Documentation* in Springer Digital Library.

Il terzo e ultimo caso studio, a scala territoriale, sintetizza le attività svolte durante i primi due anni del dottorato, coerentemente con il mio percorso formativo, per un progetto finanziato dal Ministero degli Affari Esteri e della Cooperazione Internazionale. Nello specifico, ho avuto modo di sperimentare i rilievi da drone come base di partenza per la progettazione architettonica. Alcuni dei risultati sono stati già pubblicati in *Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina* (IX Convención de Agrimensura), *SSIMM: Italy-South Africa joint Research Project: the architectural response* (II Simposio dell’Unione Italiana per il Disegno - Internazionalizzazione della Ricerca) e *Documentation and enhancement of the cultural landscape of South Africa* (D-SITE, Drones - Systems of Information on Cultural Heritage).

L’obiettivo è stato quello di digitalizzare tutte le informazioni acquisite dai diversi casi studi, analizzarle, ordinarle e catalogarle in repositori di dati digitali, per facilitare la collaborazione e la gestione in un ambiente interdisciplinare, e così, snellire i compiti e ottimizzare i processi.

Le risorse digitali, infatti, non solo facilitano e migliorano i processi scientifico-tecnologici tradizionalmente utilizzati per la protezione del patrimonio, ma cambiano anche il modo in cui il patrimonio è compreso, percepito e trasmesso, offrendo un nuovo orizzonte di strategie decisionali verso una conservazione sempre più sostenibile.

RESUMEN

El patrimonio arquitectónico y paisajístico puede definirse como la memoria material - e inmaterial - de la cultura de una comunidad. Es un recurso inmenso, pero al mismo tiempo enormemente frágil y, por desgracia, esencialmente no renovable. Su reconocimiento como tal implica una acción permanente dirigida a su conocimiento y conservación, con el fin de asegurar su correcta transmisión a las generaciones futuras.

El proyecto de investigación, en un intento de dar respuesta a estas necesidades, ha experimentado metodologías innovadoras para la gestión y el análisis de los riesgos, la vulnerabilidad del patrimonio cultural y el impacto social, temas absolutamente en línea con las áreas de investigación del Departamento de Ingeniería Civil de la Universidad de Salerno y el Curso de Doctorado en *Rischio e sostenibilità nei sistemi dell'ingegneria civile, edile ed ambientale*. De este modo, se ha tenido la oportunidad de poner de manifiesto el rol y el impacto actual de las tecnologías digitales para el conocimiento y la protección del patrimonio cultural. El primer capítulo se concentrará, por lo tanto, en definir y evaluar la importancia del patrimonio cultural como recurso sostenible para la sociedad y cómo protegerlo, considerando los posibles riesgos, desde aquellos más técnicos, hasta aquellos relacionados con el olvido y/o la pérdida de la memoria cultural.

Los avances científicos y tecnológicos que promueven estrategias para proteger el patrimonio cultural están a la orden del día: la digitalización, la modelización, la visualización y el uso de sistemas inmersivos, han adquirido un peso sin precedentes. El segundo capítulo destacará los nuevos horizontes que permiten incorporar perspectivas muy diferentes sobre el patrimonio, en las que intervienen disciplinas cada vez más especializadas, con sus propios lenguajes y algoritmos. Se presentarán las iniciativas y estrategias internacionales más contemporáneas para mejorar cualitativa y cuantitativamente, a través de las herramientas que ofrecen las tecnologías digitales, las posibilidades de acercarse al conocimiento del patrimonio cultural promoviendo nuevos sistemas para interpretarlo y conservarlo.

La metodología, que contempla el análisis, la digitalización y la fruición del patrimonio, ha sido diseñada y aplicada en tres casos de estudio potencialmente reconocibles por la UNESCO como Patrimonio de la Humanidad. A partir de una investigación documental y de la aplicación de técnicas integradas de levantamiento digital y elaboración de datos, se han desarrollado acciones que responden a las necesidades cada vez más frecuentes de la sociedad en términos de levantamiento, recuperación y conservación.

Los casos analizados no siguen un orden cronológico, sino que se presentan en un orden de escala, alejándose progresivamente del objeto. El primer caso de estudio, a escala arquitectónica, se centra en un ejemplo emblemático de la Italia medieval; el segundo caso de estudio, a escala paisajística, trata los jardines y paisajes de la Alemania barroca; finalmente, el último caso de estudio, esta vez a escala territorial, se enfoca en uno de los testimonios arqueológicos más extraordinarios de la Sudáfrica precolonial.

Para el caso de estudio principal, centrado en una arquitectura histórica simbólica del sur de Italia, Villa Rufolo en Ravello, se presenta un enfoque basado en levantamientos integrados como apoyo a HBIM (Historic Building Information Modeling) en el marco de un proyecto financiado por la Universidad de Salerno en colaboración con la entonces Dirección de Villa Rufolo. El proyecto nació de la necesidad de profundizar en el estado del conocimiento del objeto de estudio y de la idea de cómo digitalizarlo, con los primeros resultados fusionados en la monografía *Villa Rufolo. Una scoperta che dura da mille anni*. El flujo de trabajo ha sido siempre acompañado del uso y la integración de técnicas avanzadas de levantamiento digital:

según las necesidades, los objetivos y las características de complejidad, implementando diferentes enfoques y técnicas, como se presenta en la contribución en volumen *A pipeline for the integration of 3D data on aero photogrammetric frameworks. The case study of Villa Rufolo*. Sensores pasivos, como la fotogrametría UAV (Unmanned Aerial Vehicle) con apoyo GNSS (Global Navigation Satellite System), y sensores activos, como el TLS (Terrestrial Laser Scanning) y el MLS (Mobile Laser Scanning), se han integrado y utilizado como base para una posterior experimentación estratégica de un modelado HBIM multidimensional (presentado a la revista científica “disegnarecon” en *BIM Reverse modelling process for the documentation in Villa Rufolo in Ravello*). A continuación, siguiendo un proceso de ingeniería inversa, partiendo de la nube de puntos, se han modelado los elementos del caso de estudio, siguiendo una adecuada definición de prioridades y una clasificación de niveles de desarrollo, procediendo a una original profundización en el concepto de precisión y considerando una visualización realista hacia una documentación “as-built”; la técnica *Image-based Elaborations to improve the HBIM Level of Development* ha sido aceptada para su publicación en “3D Modeling & BIM”.

El segundo caso de estudio, a escala paisajística, se sitúa en Alemania y se abordó junto con la fase concluyente del proyecto de doctorado. Los paisajes cistercienses han representado un escenario interesante sobre el que probar las últimas actualizaciones de la metodología MLS, generando una infografía precisa que se ha explorado en el proyecto Cisterscapes - Cistercian Landscapes Connecting Europe; los resultados se han fusionado en la propuesta *Recording and comparing garden architecture, value of slam-based recording for research on cultural landscapes in connection with heritage conservation* presentada al International Committee of Architectural Photogrammetry CIPA ICOMOS Heritage Documentation. Además, esta estancia en el extranjero en la Universidad de Bamberg ha servido para realizar experimentaciones sobre esta nueva tecnología y conocer las mejores prácticas del instrumento, profundizando la técnica SLAM (Simultaneous Localization And Mapping) caracterizada por la rapidez en la adquisición de datos. Esta experiencia sentó las bases para la publicación *A SLAM integrated approach for Digital Heritage Documentation* en Springer Digital Library.

El tercer y último caso de estudio, a escala territorial, resume las actividades realizadas durante los dos primeros años del proyecto de doctorado, en el marco de un proyecto financiado por el Ministerio Italiano de Asuntos Exteriores y Cooperación Internacional en colaboración con la Tshwane University of Technology en Pretoria. En concreto, se ha tenido la oportunidad de experimentar estudios con drones como punto de partida para el diseño arquitectónico. Algunos de los resultados han sido publicados en *Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina* (IX Convención de Agrimensura), *SSIMM: Italy-South Africa joint Research Project: the architectural response* (II Simposio dell’Unione Italiana per il Disegno - Internazionalizzazione della Ricerca) y *Documentation and enhancement of the cultural landscape of South Africa* (D-SITE, Drones - Systems of Information on Cultural Heritage).

El objetivo era digitalizar toda la información adquirida en los diferentes casos de estudio, analizarla, ordenarla y catalogarla en repositorios de datos digitales, para facilitar la colaboración y la gestión en un entorno interdisciplinar, y así, agilizar las tareas y optimizar los procesos. Los recursos digitales, de hecho, no sólo facilitan y mejoran los procesos científico-tecnológicos tradicionalmente utilizados para la protección del patrimonio, sino que además cambian constantemente la forma de entender, percibir y transmitir el patrimonio, ofreciendo un nuevo horizonte de estrategias decisionales hacia una conservación cada vez más sostenible.

ZUSAMMENFASSUNG

Das architektonische und landschaftliche Erbe kann als das materielle - und nicht immaterielle - Gedächtnis der Kultur einer Gemeinschaft definiert werden. Es ist eine immense Ressource, gleichzeitig aber auch enorm zerbrechlich und leider nicht erneuerbar. Die Anerkennung dieser vergänglichen Eigenschaft verlangt ein andauerndes Handeln, die auf Erkenntnis und Erhaltung abzielt, um eine korrekte Weitergabe an zukünftige Generationen zu gewährleisten.

In dem Versuch, auf diese Anforderungen zu reagieren, hat das vorliegende Forschungsprojekt innovative Methoden für Management und Analyse von Risiken, Verwundbarkeit des kulturellen Erbes und sozialen Auswirkungen erforscht. Diese Themen stehen im Einklang mit den Forschungsbereichen der Fakultät für Bauingenieurwesen der Universität Salerno und der Graduiertenschule in *‚Rischio e sostenibilità nei sistemi dell'ingegneria civile, edile ed ambientale'*. Auf diese Weise hatte ich die Möglichkeit, die aktuelle Rolle und den Einfluss digitaler Technologien für das Wissen über und den Schutz von kulturellem Erbe zu beleuchten. Im ersten Kapitel werde ich mich daher darauf konzentrieren, die Bedeutung des kulturellen Erbes als nachhaltige Ressource für die Gesellschaft zu definieren und einzuschätzen, wie es zu schützen ist. Hierbei werden mögliche Risiken berücksichtigt, von eher ingenieurtechnischen Risiken bis hin zum Vergessen und/oder dem Verlust des kulturellen Gedächtnisses.

Wissenschaftliche und technologische Fortschritte, die Strategien zum Schutz des kulturellen Erbes fördern, sind das Gebot der Stunde: Digitalisierung, Modellierung, Visualisierung und der Einsatz immersiver Systeme haben einen nie dagewesenen Einfluss erlangt. Das zweite Kapitel wird die neuen Horizonte aufzeigen, die die Integration sehr unterschiedlicher Perspektiven auf das Kulturerbe ermöglichen, wobei zunehmend spezialisierte Disziplinen mit ihren eigenen Sprachen und Algorithmen einbezogen werden. Es werden die aktuellsten internationalen Initiativen und Strategien vorgestellt, um durch digitalen Technologien als Werkzeug die Möglichkeiten der Annäherung an das Wissen über das kulturelle Erbe qualitativ und quantitativ zu verbessern. Dadurch werden neue Systeme zu dessen Interpretation und Erhaltung gefördert werden.

Eine neue Methodik, die Analyse, Digitalisierung und Vermittlung des Erbes in Betracht zieht, wurde entwickelt und in drei Fallstudien angewandt, die potenziell von der UNESCO als Welterbestätten anerkannt werden könnten. Basierend auf dokumentarischer Forschung und der Anwendung integrierter digitaler Vermessungs- und Datenverarbeitungstechniken wurden Maßnahmen entwickelt, die den immer häufigeren Bedürfnissen der Gesellschaft in Bezug auf Vermessung, Wiederherstellung und Erhaltung entsprechen.

Die analysierten Fallstudien folgen keiner chronologischen Reihenfolge, sondern werden in einer massstäblichen Reihenfolge dargestellt, die sich progressiv vom Objekt wegbewegt. Die erste Fallstudie in architektonischem Maßstab, konzentriert sich auf ein emblematisches Beispiel des mittelalterlichen Italiens; die zweite Fallstudie, auf landschaftlicher Ebene, beschäftigt sich mit den Gärten und Landschaften des barocken Deutschlands; die letzte Fallstudie schließlich, diesmal auf territorialer Ebene, konzentriert sich auf eines der außergewöhnlichsten archäologischen Zeugnisse des vorkolonialen Südafrikas.

Für die Hauptfallstudie, die sich auf eine symbolträchtige historische Architektur Süditaliens, die Villa Rufolo in Ravello, konzentriert, wird ein integrierter Vermessungsansatz zur Unterstützung von HBIM (Historic Building Information Modeling) vorgestellt, die im Rahmen eines von der Universität Salerno finanzierten Projekts in Zusammenarbeit mit dem damaligen Management der Stätte vorgestellt. Das Projekt entstand aus der Notwendigkeit, den Wissensstand über das Studienobjekt zu vertiefen und aus der Idee, es zu digitalisieren. Die ersten Ergebnisse wurden in der Monographie *Villa Rufolo. Una scoperta che dura da mille anni* zusammengefasst. Der Arbeitsablauf

wurde immer von der Verwendung und Integration fortschrittlicher digitaler Vermessungstechniken begleitet: je nach Bedarf, Zielsetzung und Komplexitätsmerkmalen werden verschiedene Ansätze und Technologien implementiert, wie im Kapitel *A pipeline for the integration of 3D data on aero photogrammetric frameworks. The case study of Villa Rufolo*, vorgestellt wird. Passive Sensoren, wie z. B. Drohnen-Photogrammetrie mit GNSS-Unterstützung, und aktive Sensoren, wie der statische Laserscanner (TLS) und der dynamische Laserscanner (MLS), wurden integriert und als Grundlage für eine weitere strategische Erprobung einer mehrdimensionalen HBIM-Modellierung verwendet (vorgestellt in der Fachzeitschrift "disegnarecon" im *BIM Reverse modelling process for the documentation in Villa Rufolo in Ravello*). Anschließend wurden die Elemente der Fallstudie nach einem Reverse-Engineering-Verfahren modelliert, ausgehend von der Punktwolke. Hier wurde eine geeignete Definition von Prioritäten und eine Klassifizierung von Entwicklungsebenen vorgenommen, die zu einer originellen Vertiefung des Genauigkeits-Konzeptes unter Berücksichtigung einer realistischen Visualisierung in Richtung einer "as-built"-Dokumentation führte; die Technik *Image-based Elaborations to improve the HBIM Level of Development* wurde zur Veröffentlichung in "3D Modeling & BIM" angenommen.

Die zweite Fallstudie im Landschafts-Maßstab, befindet sich in Deutschland und wurde in Verbindung mit der Abschlussphase meiner Promotion durchgeführt. Zisterzienserlandschaften stellten eine interessantes Szenario dar, an der die neuesten Entwicklungen der MLS-Methodik getestet werden konnten. Es wurde eine genaue Infografik erstellt, die im Projekt *Cisterscapes - Cistercian Landscapes Connecting Europe* untersucht wurde; die Ergebnisse wurden in dem Publikations-Vorschlag *Recording and comparing garden architecture, value of slam-based recording for research on cultural landscapes in connection with heritage conservation* zusammengefasst, der der CIPA ICOMOS Heritage Documentation – Gruppe vorgelegt wurde. Darüber hinaus diente dieser Auslandsaufenthalt dazu, weitere Tests mit der neuen Instrumentierung durchzuführen und die besten Praktiken des Instruments kennenzulernen. Die SLAM-Technik zeichnet sich durch die Geschwindigkeit der Datenerfassung aus. Diese Erfahrung legte den Grundstein für die Veröffentlichung *A SLAM integrated approach for Digital Heritage Documentation* in Springer Digital Library.

Die dritte und letzte Fallstudie auf territorialer Ebene fasst die Aktivitäten zusammen, die im Rahmen eines vom italienischen Ministerium für auswärtige Angelegenheiten und internationale Zusammenarbeit finanzierten Projekts durchgeführt wurden. Insbesondere hatte ich die Möglichkeit, mit Vermessungen durch Drohnenaufnahmen als Ausgangspunkt für architektonisches Design zu experimentieren. Einige der Ergebnisse wurden bereits veröffentlicht in *Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina* (IX Convención de Agrimensura), *SSIMM: Italy-South Africa joint Research Project: the architectural response* (II Simposio dell'Unione Italiana per il Disegno - Internazionalizzazione della Ricerca) und *Documentation and enhancement of the cultural landscape of South Africa* (D-SITE, Drones - Systems of Information on Cultural Heritage).

Ziel dieses Forschungsprojektes war es, alle aus den verschiedenen Fallstudien gewonnenen Informationen zu digitalisieren, zu analysieren, zu ordnen und in digitalen Datenrepositorien zu katalogisieren, um die Zusammenarbeit und das Management in einem interdisziplinären Umfeld zu erleichtern und damit Aufgaben zu straffen und Prozesse zu optimieren. Digitale Ressourcen erleichtern und verbessern nicht nur die wissenschaftlich-technischen Prozesse, die traditionell für den Schutz des Kulturerbes eingesetzt werden, sondern verändern auch ständig die Art, wie Kulturerbe verstanden, wahrgenommen und weitergegeben wird. Sie bieten eine neue Dimension von Entscheidungsstrategien für eine zunehmend nachhaltige Erhaltung.

RESUMO

O património arquitectónico e paisagístico pode ser definido como a memória tangível - e intangível - da cultura de uma comunidade. É um recurso imenso, mas ao mesmo tempo enormemente frágil e, infelizmente, essencialmente não renovável. O seu reconhecimento como tal implica uma acção permanente que visa o seu conhecimento e conservação, a fim de assegurar a sua transmissão correcta às gerações futuras.

Numa tentativa de responder a estas necessidades, o projecto de investigação experimentou metodologias inovadoras para a gestão e análise de riscos, vulnerabilidade do património cultural e impacto social, temas absolutamente em linha com as áreas de investigação do Departamento de Engenharia Civil da Universidade de Salerno e do Curso de Doutoramento em *Rischio e sostenibilità nei sistemi dell'ingegneria civile, edile ed ambientale*. Desta forma se destacou o actual papel e impacto das tecnologias digitais para o conhecimento e protecção do património cultural. O primeiro capítulo, portanto, concentra-se na definição e avaliação da importância do património cultural como um recurso sustentável para a sociedade e a forma de protegê-lo, considerando os seus possíveis riscos, desde os mais técnicos, até o esquecimento e/ou perda da memória cultural.

Os avanços científicos e tecnológicos que promovem estratégias para proteger o património cultural estão na ordem do dia: a digitalização, a modelação, a visualização e a utilização de sistemas imersivos adquiriram um peso sem precedentes. O segundo capítulo destaca os novos horizontes que permitem a incorporação de perspectivas muito diferentes sobre o património, envolvendo disciplinas cada vez mais especializadas, com as suas próprias línguagens e algoritmos. Apresenta as iniciativas e estratégias internacionais mais contemporâneas para melhorar qualitativa e quantitativamente, através das ferramentas oferecidas pelas tecnologias digitais, as possibilidades de abordar o conhecimento do património cultural, promovendo novos sistemas de interpretação e conservação do mesmo.

A metodologia, que contempla a análise, digitalização e fruição do património, foi concebida e aplicada em três estudos de caso potencialmente reconhecíveis como sítios do Património da Humanidade pela UNESCO. Com base na investigação documental e na aplicação de técnicas integradas de levantamento digital e processamento de dados, têm sido desenvolvidas acções que respondem às necessidades cada vez mais frequentes da sociedade em termos de levantamento, recuperação e conservação.

Os estudos de caso analisados não seguem uma ordem cronológica, mas são apresentados numa ordem de escala, afastando-se progressivamente do objecto. O primeiro estudo de caso, à escala arquitectónica, centra-se num exemplo emblemático da Itália medieval; o segundo estudo de caso, à escala da paisagem, trata dos jardins e paisagens da Alemanha barroca e finalmente, o último estudo de caso, desta vez à escala territorial, centra-se num dos mais extraordinários testemunhos arqueológicos da África do Sul pré-colonial.

Para o estudo de caso principal, centrado numa arquitectura histórica simbólica do sul de Itália, Villa Rufolo em Ravello, é apresentada uma abordagem integrada em apoio à HBIM (Historic Building Information Modeling) no âmbito de um projecto financiado pela Universidade de Salerno em colaboração com a atual Direcção de Villa Rufolo. O projecto nasceu da necessidade de aprofundar o estado de conhecimento do objecto de estudo e da ideia de como digitalizá-lo, com os primeiros resultados obtidos na monografia *Villa Rufolo - Una scoperta che dura da mille anni*. O fluxo de trabalho tem sido sempre acompanhado pela utilização e integração de técnicas avançadas de levantamento digital: de acordo com as necessidades, objectivos e características de complexidade, implementando diferentes abordagens e técnicas, tal como apresentado na

contribuição no volume *A pipeline for the integration of 3D data on aero photogrammetric frameworks. The case study of Villa Rufolo*. Sensores passivos, como a fotogrametria de UAV (Unmanned Aerial Vehicle) com suporte GNSS (Global Navigation Satellite System), e sensores activos, como o TLS (Terrestrial Laser Scanning) e o MLS (Mobile Laser Scanning), foram integrados e utilizados como base para uma nova experimentação estratégica de uma modelação HBIM multidimensional (apresentada à revista científica "disegnarecon" no *BIM Reverse modelling process for the documentation in Villa Rufolo in Ravello*). Depois, seguindo um processo de engenharia inversa, partindo da nuvem de pontos, os elementos do estudo de caso foram modelados, seguindo uma definição adequada de prioridades e uma classificação de níveis de desenvolvimento, procedendo a um aprofundamento original do conceito de precisão e considerando uma visualização realista em direcção a uma documentação "as-built"; a técnica *Image-based Elaborations to improve the HBIM Level of Development* foi aceito para publicação em "3D Modeling & BIM".

O segundo estudo de caso, à escala paisagística, está localizado na Alemanha e foi realizado em conjunto com a fase de conclusão do doutoramento. As paisagens de Cister representam um cenário interessante para testar as últimas actualizações da metodologia MLS, gerando um infográfico preciso que foi explorado no projecto Cisterscapes - Cistercian Landscapes Connecting Europe. Os resultados foram reunidos na proposta *Recording and comparing garden architecture, value of slam-based recording for research on cultural landscapes in connection with heritage conservation,* apresentada ao CIPA ICOMOS Heritage Documentation. Além disso, esta estadia no estrangeiro serviu para realizar mais testes sobre este novo instrumento e para conhecer as melhores práticas do instrumento, aprofundando-se na técnica SLAM (Simultaneous Localization And Mapping) caracterizada pela velocidade de aquisição de dados. Esta experiência lançou as bases para a publicação *A SLAM integrated approach for Digital Heritage Documentation* na Springer Digital Library.

O terceiro e último estudo de caso, à escala territorial, resume as actividades realizadas durante os dois primeiros anos do doutoramento, de acordo com a formação academica, no âmbito de um projecto financiado pelo Ministério Italiano de Relaciones Exteriores e da Cooperação Internacional. Em particular, nesse caso teve-se a oportunidade de experimentar estudos com drones como ponto de partida para a concepção arquitectónica. Alguns dos resultados já foram publicados em *Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina* (IX Convención de Agrimensura), *SSIMM: Italy-South Africa joint Research Project: the architectural response* (II Simposio dell'Unione Italiana per il Disegno - Internazionalizzazione della Ricerca) e *Documentation and enhancement of the cultural landscape of South Africa* (D-SITE, Drones - Systems of Information on Cultural Heritage).

O objectivo foi digitalizar toda a informação adquirida a partir dos diferentes estudos de caso, analisá-la, ordená-la e catalogá-la em repositórios de dados digitais, a fim de facilitar a colaboração e a gestão num ambiente interdisciplinar, para assim racionalizar tarefas e optimizar processos. De facto os recursos digitais não só facilitam e melhoram os processos científico-tecnológicos tradicionalmente utilizados para a protecção do património, mas também mudam constantemente a forma como o património é compreendido, percebido e transmitido, oferecendo um novo horizonte de estratégias de tomada de decisão no sentido de uma conservação cada vez mais sustentável.

TABLE OF CONTENTS

La historia deja su huella en nosotros para toda la existencia.

Marc Ferro.

1. INTRODUCTION

1.1. Cultural Heritage definition: continuously evolving over time

Architectural heritage can be defined as the living memory of the culture of people. It is a huge resource, but enormously fragile and unfortunately essentially non-renewable. For this reason, its recognition implies a continuous action, aimed at its knowledge and conservation, to ensure its transmission to future generations, looking towards its sustainable development.

In recent times, the sustainable conservation of Cultural Heritage[1] has become an imperative global challenge. Even though its fragility, Cultural Heritage is an important factor in maintaining cultural diversity in the face of increasing globalization and the constantly changing nature of today's society. Understanding the tangible and intangible Cultural Heritage of different communities contributes to dialogue and promotes respect between and among different cultures.

Perhaps the most accepted definition of Cultural Heritage, according to Code of the Cultural and Landscape Heritage[2], consists of the immovable and movable things which present artistic, historical, archaeological, ethnoanthropological, archival and bibliographical interest, and of any other thing identified by law or in accordance with the law as testifying to the values of civilization. Although the definition of Cultural Heritage is continuously evolving over time, it is certainly becoming an element of unquestionable importance. Today it is clear the change in society's attitude towards the legacy received from previous generations. The explanation for this change in perception is related to several factors, such as the accelerated pace of modernization at the same time as the need for transcendence of the community's cultural memory caused by the feeling of abandonment of local traditions.

In order to promote the conservation of Cultural Heritage, it is proposed to favor an appropriation increasingly felt by the community and thus spread the value and the duty of its protection, based on proposals for the enhancement and expanded fruition of heritage, which ensure the best conditions for its use and enjoyment.

Research will be conducted to promote a social context in which the heritage received from previous generations contributes to reinforce the cultural identity of the community and materializes as the necessary reference respecting a rapidly changing world, in accordance with the proverb "to build the future we must look to the past".[3]

For simplicity of reading of the Thesis, it has been decided to list the notes by simple page.

[1] Cultural and natural heritage are defined in Articles 1 and 2 of the World Heritage Convention. The following shall be considered as "Cultural Heritage":
- Monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of Outstanding Universal Value from the point of view of history, art, or science.
- Groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity, or their place in the landscape, are of Outstanding Universal Value from the point of view of history, art, or science.
- Sites: works of man or the combined works of nature and of man, and areas including archaeological sites which are of Outstanding Universal Value from the historical, aesthetic, ethnological or anthropological points of view.

[2] Code of the Cultural and Landscape Heritage, Italian Legislative Decree 22 January 2004 n. 42.

[3] Otto Frank, 1967.

1.2. Cultural Heritage need for conservation: a duty of society

Cultural Heritage is an important factor in the quality of life of society

Only at the end of the 60's of the last century[1] people began to think about historical heritage as one of the main factors improving the quality of life of citizens. According to the Council of Europe[2], Cultural Heritage is a set of resources inherited from the past that people identify, regardless of their ownership, as a reflection and expression of their continuously evolving values, beliefs, knowledge, and traditions. It is currently considered as a valuable resource to contribute to economic growth, employment, and social cohesion.

The European official statistics suggest that Cultural Heritage is a game changer factor in defining places as a location where people can live, work, and visit. For instance, in Europe, more than 8 out of 10 citizens think that CH is important for them personally, while 8 out of 10 citizens think that CH is important for the European Union. The same proportion agree that European CH and related activities create countless jobs in the continent.[3]

Some considerations are taken about the importance of Cultural Heritage in the creation of an active citizenship and its ability to create a sense of belonging and local pride. According to the Universal Declaration of Human Rights (Art. 27), everyone has the right to freely participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits. The purpose of the valorization is the diffusion and knowledge of the historical artistic cultural testimonies to promote their enjoyment. Hence, to stimulate culture development, activities are aimed to promote awareness of heritage, and to ensure the best conditions of use and access to that heritage by community.

Cultural Heritage represents a great potential for economic growth, generates value and thus benefiting citizens directly. Improving the diffusion and the involvement of local communities in heritage awareness can foster identities, strengthen communities, and support local business and sustainable development. An improved balance between the conservation of Cultural Heritage and sustainable socioeconomic development needs to be achieved.

Therefore, a process involving specialists from various sectors will need to be outlined in order to try to apply a contemporary methodology for the use, management, and protection of heritage, while preserving its historical value[4]; and at the same time contribute to the consolidation of an international cooperation network of professionals specialized in various areas of management of Cultural Heritage.[5]

---

[1] After Venice Charter, 1964.

[2] https://www.coe.int/en/web/conventions/ (last accessed March 2021).

[3] Special Eurobarometer 466: Cultural Heritage.
http://data.europa.eu/euodp/en/data/dataset/S2150_88_1_466_ENG (last accessed March 2021).

[4] According to the United States National Historic Preservation Act, 1966, historical value preservation includes "identification, evaluation, recordation, documentation, curation, acquisition, protection, management, rehabilitation, restoration, stabilization, maintenance, research, interpretation, conservation, and education and training regarding the foregoing activities or any combination of the foregoing activities".

[5] This is a recurrent target in all the last online conferences on Cultural Heritage during Covid-19 lockdown.

How to ensure Cultural Heritage fruition over time?

This is where technology comes into play: with its numerous solutions, it makes every place and every form of art more accessible to everyone, as well as stimulating especially younger users to approach what is unknown to them (Fig. 1). As Carl Sagan said, “Knowing the past to understand the present”, especially true when we look at the timeline of history and its effects on the world of today and tomorrow. Technology also contributes today, even more than a few years ago, to the formation of the right of citizenship to culture and even before serving to make heritage accessible, they have served to improve research, investigation, and protection of artistic Cultural Heritage, making more effective new solutions available to experts.

The road taken for the fruition, enhancement and enjoyment of Cultural Heritage is full of new high-tech solutions that have the use of information technology as a constant and as a goal to renew or create a change that leads to progress in this field.

The trend towards digitization promotes viable alternatives for experimenting with ever more innovative conservation strategies. Digital technologies at the service of heritage not only enhance the process of digitization and establish new pedagogical frontiers, but also change the way people understand, interpret, and transmit it to future generations. Moreover, digital technologies offer a new horizon of strategies to the decision-making about sustainable conservation over time.

The goal of Cultural Heritage management is to convey its significance and raise awareness of the need for its conservation in society. This is the task of enhancement, which plays a fundamental role in regulating physical, intellectual, and emotional access to cultural assets, thus enabling not only the cultural but also the economic development of the community. As repeatedly expressed by the European Commission “Learning from the past, designing our future”.

In times of innovation, where one finds oneself rethinking the way in which one lives, studies, works, and travels, this interdisciplinary and digital vision of heritage conservation is the key tool for changing society’s view of the value of culture. The aim is to move towards greater attention to the expectations and needs of the society and to promote Cultural Heritage in the best way possible, taking into consideration the importance of tourism in the economic context of the community. In this way, new ways of preserving Cultural Heritage are encouraged.

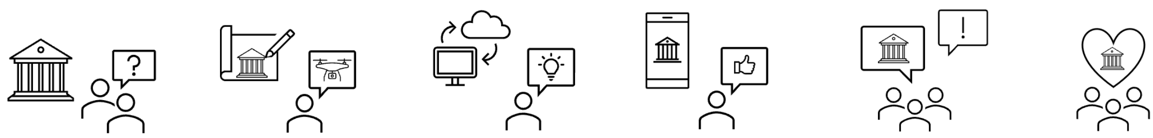


Fig. 1. Scheme on the significance of heritage digital conservation.[1]

[1] If not indicated otherwise, images by the author.

1.3. Cultural Heritage as a source of income: cultural tourism

The link between culture and tourism has resulted in Cultural Tourism, in which knowledge of monuments and historical sites is combined with the immersion in natural and cultural history, with the knowledge of the arts, philosophy and way of life of the different societies. In fact, in 1954 the European Commission of Tourism specified that the landscapes, monuments, cities, and customs constituted the tourist capital.

Since few years ago, tourism has no longer been a product reserved only for people with economic resources, but it was recognized as a requirement and even a right that also contributes to the development of community, countries, and regions.[1]

Cultural Heritage should be recognized by its capacity not just as a valuable tourism resource but also as an important and largely irreplaceable form of capital (cultural, social, environmental and economic) to be widely used, preserved, sustained and enhanced instead of being irretrievably consumed by tourism (Loulanski & Loulanski, 2011).

Hence, the social, environmental, and economic value of Cultural Heritage cannot be denied. Not only does it allow us to connect with the past, providing a sense of identity and belonging, but it is also considered an important source of employment and income (Historic England, 2019). It has a strong role in enhancing community cohesion.

Cultural Tourism is a form of tourism that focuses on the cultural aspects of a place, such as culture, Cultural Heritage, cultural landscapes, and cultural offerings, with these being the visitor's main motivation when selecting a destination. To support this point, according to the Eurobarometer[2], 68 % of Europeans agree that the presence of Cultural Heritage can strongly influence their holiday destination.

Creating meaningful cultural experiences for the public should be the primary aim of Cultural Tourism. A high level of knowledge must be present to establish these experiences, which can be achieved through collaboration between specialists in different fields.[3] Cultural Tourism then is emerging as an effective tool to make known, preserve and enjoy the Cultural Heritage of each country, and it is necessary to seek strategies aimed at promoting the development of Cultural Tourism, not only as an economic system, but also as a partner in the preservation of Cultural Heritage, always from a perspective that ensures respect and conservation of these through greater knowledge among tourists, and intercultural exchanges that contribute to economic, social and cultural development.

The overall objective of tourism management strategies includes conserving Cultural Heritage; promoting access to it and enhancing the visitor experience; informing and educating the public about the site and its significance. That should be structured with vision, targets and applicable methods determined by stakeholders for protection, restoration, education, awareness, recognition and promotion (Gültekin & Özbek Çetin, 2020).

Technologies can play a crucial role for the preservation and protection of Cultural Heritage as well as for their fruition, enhancement and tourism in close synergy between cultural and creative industries, producers and users of Cultural Heritage, e.g., continuous monitoring and preventive restoration of the sites, immersive proposals experiences, virtual tours and customization of services to better meet the demand, services for tourists, among many

[1] Situation currently changed due to Covid-19 restrictions.
[2] Special Eurobarometer 466: Cultural Heritage. http://data.europa.eu/euodp/en/data/dataset/S2150_88_1_466_ENG (last accessed March 2021).
[3] The Escape Project. https://projectescape.eu/ (last accessed March 2021).

other applications that allow to gain knowledge and to improve user's experience with Cultural Heritage.

In these times of rapid cultural transformations, the aim must be to aspire to a sustainable, inclusive, and transparent future, with the culture as a resource (Fig. 2). Looking towards a Sustainable Cultural Tourism, that can be defined as the integrated management of Cultural Heritage and Tourism activities in conjunction with the local community. Creating social, environmental, and economic benefits for all stakeholders to achieve tangible Cultural Heritage conservation and sustainable tourism development.[1]

Sustainable Cultural Tourism places Cultural Heritage and their communities at the center of the decision-making process. It requires the involvement of stakeholders and local communities to ensure that the benefits increase to both the Cultural Heritage and the people. The objective is to ensure good conservation practice along with authentic interpretation, while at the same time support the local economy.[2]

Fig. 2. Frame of the UNESCO initiative video "a world without culture is a world without a future".

[1] UNESCO, 2019. The UNESCO World Heritage and Sustainable Tourism Program represents a new approach based on dialogue and stakeholder cooperation where planning for tourism and heritage management is integrated at a destination level, the natural and cultural assets are valued and protected, and appropriate tourism developed. It is the determinant of heritage management policies and strategies.

[2] New sustainable Cultural Tourism offers, relating to both the tangible and intangible Cultural Heritage, should place an emphasis on national strategic planning and networking, as well as concepts such as 'slow' tourism, 'authenticity', 'storytelling', 'well-being' and contact with locals. Slow Tourism is a concept that challenges perceptions of travel and tourism, as it focuses on the journey as being integral to the tourist experience. It has implications for individual social responsibility in terms of effects on the environment, and promotes deeper experiences, improving cultural understanding and knowledge.

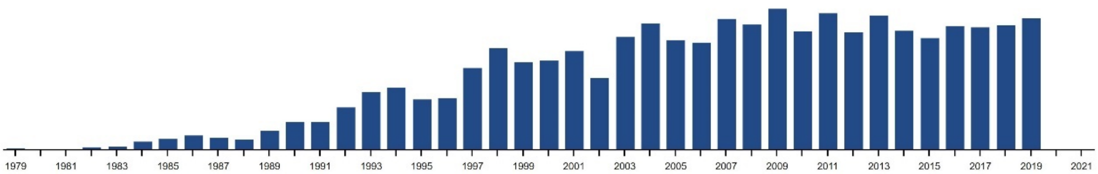


Fig. 3. Representation of quantity of properties examined each year.

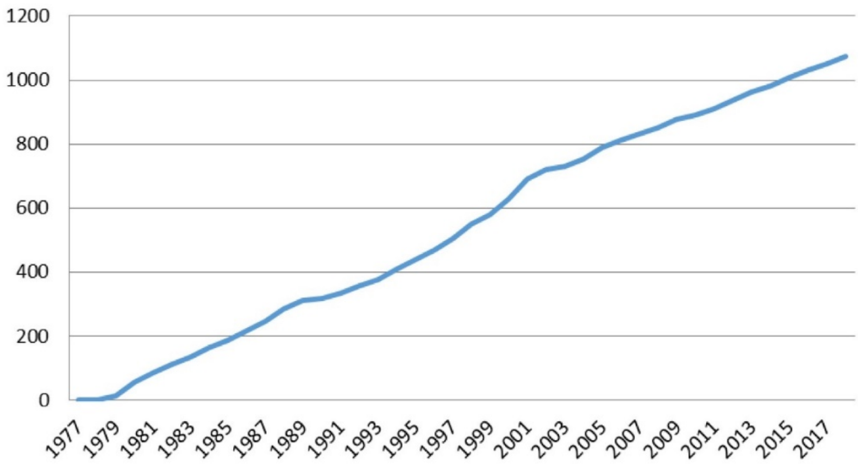


Fig. 4. Growth in the Number of properties on the World Heritage List.

Fig. 5. World Heritage Sites UNESCO, in red those in Danger.[1]

[1] https://whc.unesco.org/en/danger/ (last accessed March 2021).

1.4. Cultural Heritage at risk: conventional threats

While tourism can be an excellent tool to provide access to Cultural Heritage (Figs. 3, 4), many tourism destinations were - before current restrictions - facing serious challenges relating to over tourism, including overcrowding, massification, cultural appropriation and loss of authenticity. This was contributing to a rejection of tourism by local citizens and cultural and heritage experts, who warned about the negative effects this phenomenon may have on Cultural Heritage.

This cultural phenomenon, called over tourism, occurs when the maximum number of people allowed visit a tourist destination at the same time, without causing destruction of the physical, economic, and socio-cultural environment and an unacceptable decrease in the quality of visitors' satisfaction is exceeded.[1]

Moreover, over the years, historical Cultural Heritage has been threatened by human conflicts, natural disasters, and unexpected accidents (Fig. 5). For instance, the recent devastating events at Notre Dame[2] remind us that Cultural Heritage is constantly at risk, today as throughout history.

As previously mentioned, Cultural Heritage is the physical manifestation of the people's history and therefore constitutes an important part of its identity. Then, the destruction of Cultural Heritage is not just the damage of exceptional monuments, sites, or objects, but rather a severe disruption of a vigorous past with its existing historical places, customs, and behaviors. The damage of heritage, in an attempt to eliminate traces of a community's past, is often used as an instrument of ethnic and sectarian violence. It constitutes an established violation of human rights. Unfortunately, in society nowadays this type of damage is continued. Referring, for example, to the on-going conflict between Armenia and Azerbaijan that are currently endangering treasures of human history.[3]

Looking at Notre Dame in flames in 2019 emphasizes the importance of documenting a tangible Cultural Heritage in 3D before disasters strikes or time takes an irreversible role. In accordance, the *Research Center of Applied Science and Technology for Cultural Heritage* at the University of Bamberg[4], carried out a survey of the cathedral few days before the fire. These acquired data are currently being used in the restoration project, proving how important it is to have a technical-scientific documentation of the current state of the monuments, which serves as a basis for protecting them and promoting future management and maintenance interventions.

The digitization of the heritage is, therefore, an engineering intervention of defense against the events that may affect a given architectural work. Scientific methods and technological tools can be employed to document, investigate, and ultimately understand heritage loss in order to create more effective humanitarian policy responses and develop preventive measures.

The practice of recording and digitizing Cultural Heritage sites is gaining ground among conservation scientists and scholars in architecture, computer science, and related fields. The preceding paragraphs have highlighted the urgent need for documenting heritage sites for preservation and posterity. This process is not limited to digitization, however, but also includes the meaningful interpretation of sites with respect to their intangible values.

---

[1] UNWTO 2019 '*Over tourism*'? Understanding and Managing Urban Tourism Growth beyond Perceptions. https://www.e-unwto.org/ (last accessed March 2021).
[2] https://whc.unesco.org/en/news/1956 (last accessed March 2021).
[3] https://www.theartnewspaper.com/news/monuments-in-line-of-fire-in-nagorno-karabakh-conflict; https://www.nytimes.com/2020/11/30/opinion/armenia-azerbaijan-monuments.html (March 2021).
[4] https://www.uni-bamberg.de/presse/pm/artikel/notre-dame-kooperationsvertrag-wiederaufbau/; https://www.nationalgeographic.com/adventure/article/150622-andrew-tallon-notre-dame-cathedral-laser-scan-art-history-medieval-gothic (last accessed March 2021).

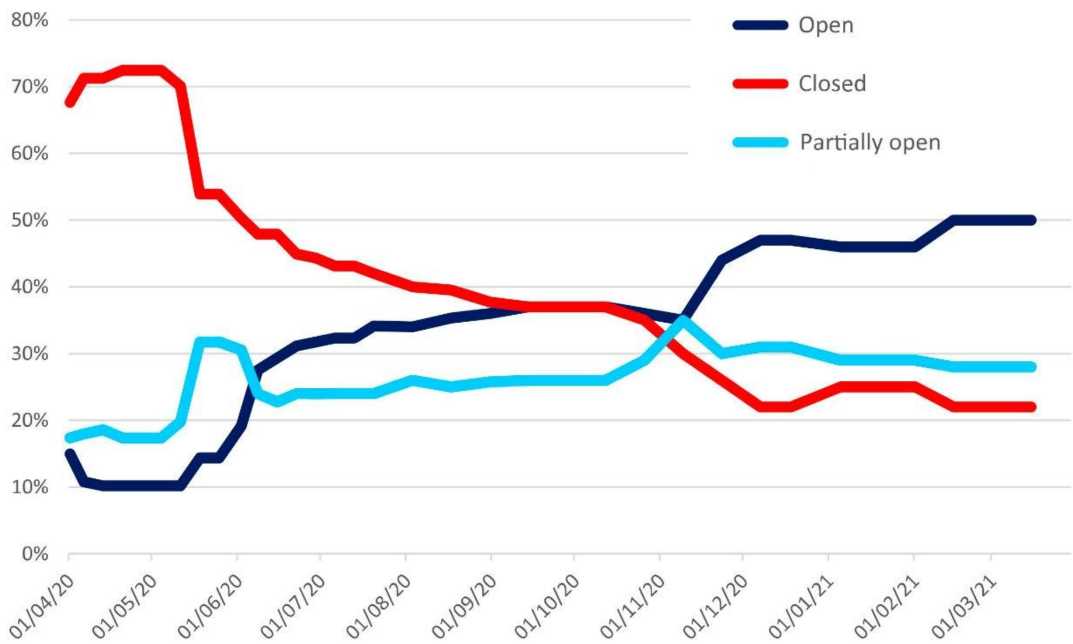


Fig. 6. Trend lines of the closure of World Heritage sites due to Covid-19. Status as of March 2021.

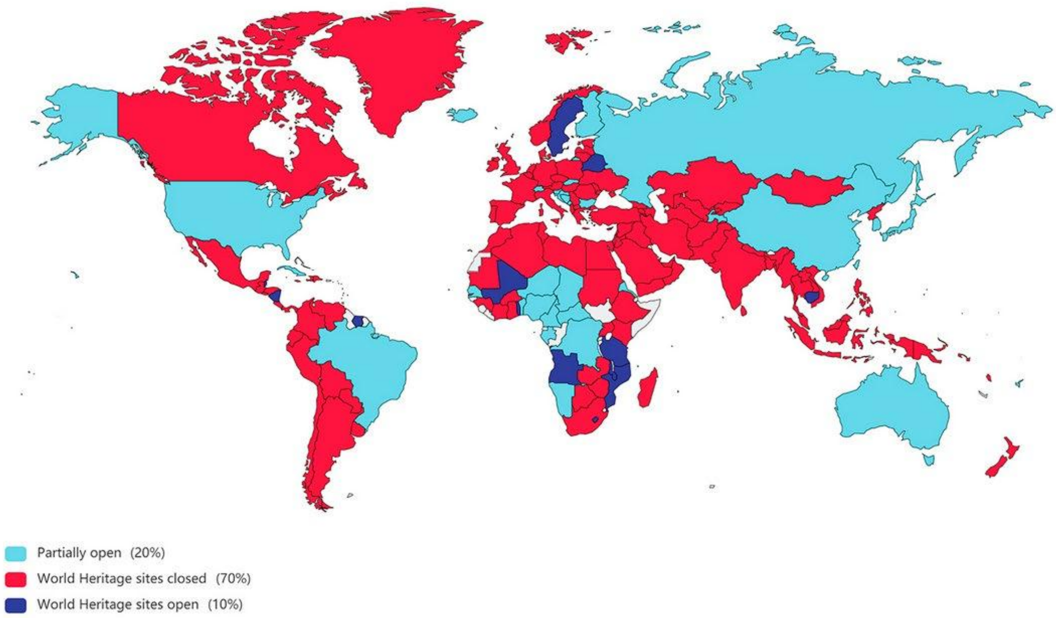


Fig. 7. Map on the closure of World Heritage sites due to Covid-19. Status as of 11 May 2020.[1]

[1] https://whc.unesco.org/en/news (last accessed March 2021).

1.5. Cultural Heritage at risk: unconventional threats, Covid-19

For years the Cultural Heritage sector, has undergone the problems related to over tourism, often unsustainable, disinterested and/or indifferent to real knowledge and conservation policies. Often also causing damage to the structures. Today, however, Cultural Heritage is facing another kind of risk; circumstances have changed. The coronavirus pandemic that is affecting the entire world population has completely changed the way we live, work and travel. Among the many sectors affected there is, without doubt, culture, and tourism (Figs. 6, 7).

Today, that over tourism is a theme that is now far from us, Cultural Heritage is in the opposite situation: in fact, according to research conducted by UNESCO[1] the 89% of the world's cultural sites have closed their doors, and probably more than 10% will not be able - at present - to reopen them again except with main investments or changes of direction (Fig. 8).

"At this moment, 89% of all World Heritage properties are totally or partially closed. Museums and other cultural institutions are losing millions in revenue each day. Artists all around the world are unable to make ends meet. UNESCO is mobilizing the international community to increase access to culture and heritage online, to support the resilience of artists and to bring governments together to find policy solutions". [2]

This has generated considerable damage to the cultural sector and to local communities whose economy is closely linked to this sector. There has been a massive negative economic impact due to the loss of entrance fees to sites and visitor centers, a source of income that is often critical for funding conservation activities. The general stop of the international and national tourism has resulted in a substantial loss of income for site management authorities. Tourism was also greatly affected by the decline in demand for accommodation, restaurants, and products of cultural industries. No one had included a pandemic in their risk assessments and therefore possibilities to ensure the continuity of services are being currently studied.

The Covid-19 crisis has prompted World Heritage Sites to develop innovative approaches and has highlighted the importance of museums in efforts to navigate and transcend the constraints imposed by the current lockdown. It is possible to observe that other new possibilities for innovation have been opened. For example, today, according to research conducted by the Network of European Museum Organizations[3], 60% of cultural sites have demonstrated resilience by starting to design creative strategies to make their spaces, collections, and exhibitions available and usable online, innovating and pushing to experiment with new digital solutions and attracting public and private funding.

This led us to further reflect on the important role that digital technologies can play in Cultural Heritage conservation, enhancement, and fruition.

According to the Report 2020 of the United Nations, the tourism is one of the economic sectors most affected by the Covid-19 pandemic due to the closure of borders, travel bans and lockdown measures. International travel arrivals in 2020 decreased more than 80% compared with 2019. The effects of the crisis on these economies will spill over to other countries, particularly those that are heavily dependent on international tourism (Fig. 9).

---

[1] https://en.unesco.org/covid19/cultureresponse/monitoring-world-heritage-site-closures (March 2021).
[2] Ernesto Ottone, Assistant director-General Culture, UNESCO. 10 July 2020.
[3] The Network of European Museum Organizations (NEMO) was founded in 1992 as an independent network of national museum organizations representing the museum community of the member states of the Council of Europe. www.ne-mo.org (last accessed March 2021).

Fig. 8. Current tourism challenges of UNESCO, World Heritage site closures.

Fig. 9. Current tourism challenges of UNESCO, tourism sector under threat.

Has Covid-19 accelerated digital transformation?

“We are not living an Era of Change but a Change of Era”.

As we had the opportunity to hear from Peter Paul Verbeek[1], digital technologies can play an important role in the fight against pandemics: they help to monitor, anticipate, influence the spread of disease, as well as the behavior of human beings. Thus, *how can we deal with technologies in a responsible way?* This provocation makes us to reflect on our current use of technology. For instance, in these difficult times, it is because of technology that we have been able to mobilize ourselves, to work, to communicate. The world has come to a stop for several months, and *which is the benefit of it?* Perhaps this is a good opportunity to finally resolve some unfinished issues.

Analyzing the common good, according to the context of the Thesis, these technologies should also serve to protect our heritage for the next generation. For example, the trend towards digitization will also offer significant new opportunities for the tourism sector, for immediate recovery and resilience and, in the long term, for greater sustainability. To favor accessibility and fruition to Cultural Heritage is preventing social distancing. Because access to information opens new frontiers towards the education and enhancement. It has been demonstrated that people need culture as an engine and a driving force for personal and collective well-being.

Today we are facing the most important crisis of the last century. Our habits have changed, and digitalization, automatization, connection, collaboration, innovation are today’s *hashtags*. Technological acceleration is trend in all sectors. Also, in the sector of Cultural Heritage. Advanced technologies, such as artificial intelligence (AI)[2], augmented reality (AR) and virtual reality (VR), bring unprecedented opportunities, today, to digitize Cultural Heritage, for preservation, conservation, restoration, research, (e.g., AI for classification of materials for conservation, monitoring and understanding of human behavior, mobile robotics for museums, control, inspection) as well as for a broader, more democratic online access and re-use by various sectors, such as tourism (e.g., AI for tourist entertainment, content generation, visualization).

Digital technologies can help in the reconstruction of damaged Cultural Heritage and they can also help to increase the number of people accessing Cultural Heritage online. In these fields, we have seen upcoming trends such as open access, streaming, interoperability, interactivity, virtual museums, among others. Digital preservation of Cultural Heritage is important to society. It can be useful for creating digital twins of historical architectures, monuments, and sites such as Notre Dame, before they are damaged by fire or other disasters. It can be useful for creating high-quality 3D models of cultural objects before they are lost, or 3D models of cultural sites for online visualization and communication. Also, they are useful to promote immersive emotional experiences.

As mentioned before, Cultural Heritage at risk promotes the critical need to take full advantage of digital technologies to record, document and preserve it and promote its accessibility to citizens. At the same time, open, interoperable, and high-quality access to Digital Cultural Heritage assets is essential to create greater digital engagement for audiences and encourage their use in applications that promote the tourism, education, creative industries, and other sectors. This Thesis seeks to highlight some of the cutting-edge scientific methods, technologies and research projects that are being carried out to overcome cultural tragedies.

[1] Chairman of UNESCO’s World Commission on the Ethics of Scientific Knowledge and Technology.

[2] “AI is going to make our lives better in the future”. Mark Zuckerberg, CEO of Facebook.

How is digital revolution reshaping our world?

“Our lifestyles will undergo radical changes in the coming years as a result of the stresses we have experienced in recent years, and we must be prepared for these changes”.[1]

Digital technologies based on hardware, software and network devices are not brand new, but unlike what happened in the third industrial revolution, they are characterized by a higher level of integration and sophistication, thus contributing to the transformation of society and world economies. For this reason, and to define this period, professors at MIT, introduced the famous expression the machine of the second era, underlining the crucial moment of progress, in which the impact of digital technologies would manifest itself ‘in full force’ through automation and the realization of ‘unprecedented things’[2]. Information and communication technologies (ICTs) must become a means to drive, implement and develop effective public policies.

In every revolution there is a precise moment that represents the beginning and marks the point of no return: it is the moment when change, which until then has remained covert and barely visible, becomes unpredictable and imposes itself as an unstoppable phenomenon, destined to change forever the frame of reference for all, and not just for a few.

The technological trend is heading towards a fourth industrial revolution, with the development and advancement of artificial intelligence. Concepts such as computer vision, machine learning, language processing, virtual assistance or robotics are becoming more and more current and are imposing a - *peaceful?* - transition towards the digital world, i.e., everything that can be digitized will be digitized, everything that can be automated will be automated.

Emerging technologies, such as big data, artificial intelligence, and augmented reality, offer numerous possibilities for further processing and utilization of Digital Cultural Heritage. 3D technologies are particularly promising, offering new ways to advance scientific understanding, manage and restore damaged or fragile heritage, and ensure digital conservation that reflects the uniqueness and multidimensionality of our heritage. 3D is also one of the foundations of interactive technologies such as virtual and augmented reality for cultural applications. They are tools that allow the use and reuse of Digital Cultural Heritage in innovative ways to face future challenges.

Nowadays, society is crossing another revolution in the middle of a major transformation concerning the way products are produced. This is due to the digitization of manufacturing. This evolution is so captivating that it is being called Industry 4.0 to characterize the fourth revolution that has occurred in manufacturing. It is expected that the key drivers of the Industry 4.0 will be: 3D printing, augmented reality, big data analytics and advanced algorithms, cloud computing, location detection technologies, smart sensors, and all of them will have a decisive influence on data collection, management, and communication.

The digital era has unleashed innovative ways - unthinkable a couple of years ago - to explore Cultural Heritage, and thus preserve our collective memory. Through the consolidation of an optimized process of integration of new digital survey techniques. By exploring data processing and 3D visualization technologies, continued innovation in the way we archive, study, and disseminate our history, architectural and archaeological heritage is foreseen.

[1] Massachusetts Institute of Technology (MIT) review, Gideon Lichfield, 2020.

[2] Brynkolfsson & McAfee, 2014. The second machine age: Work, progress, and prosperity in a time of brilliant technologies.

1.6. Cultural Heritage in digital: virtual cultural tourism

Throughout this Thesis several international initiatives for the preservation of Cultural Heritage for the next generations will be discussed, all of them focused on the digital transition.

One of the powers of culture is to bring hope and hold the community together in particularly difficult times; this is precisely why more than a few institutions, museums, organizations, have shared, in the last months, its virtual contents around the world.

In the context of limited mobility, 3D digital technologies, as expressed in the European Commission's strategic reports[1], can be an effective solution for keeping Cultural Heritage - World Heritage Sites - accessible to all (Fig. 10). Their digitization will also offer significant new opportunities for the tourism sector, for its immediate recovery and resilience and, in the long term, for greater sustainability.

Cultural Heritage will become a source of inspiration for new creations and an opportunity to rethink the future, during the present, considering the past. It is sought to foster access to our heritage to promote diversity, inclusion, creativity and critical engagement through the exchange and dissemination of knowledge. Through collaborative projects that strengthen capacity for innovation, promoting the use of digital technology to tell stories, and to foster the transcendence of culture, establishing a solid foundation for community and future generations.

Sectors as research, education, tourism, and creative industries, can be hugely influenced by digital technologies. They can empower and encourage the community into more active and creative cultural participation. Important aspects of digital transformation in the Cultural Heritage sector are seen by means of the adoption of advanced digitization technologies, the acquisition of advanced digital skills, online access to digitized content, the organization of virtual online exhibitions, the use of digitized content in immersive experiences with the help of interactive technologies such as extended reality and the creation of a more agile digital environment.

Fig. 10. Cultural Heritage in Digital.

[1] https://ec.europa.eu/digital-single-market/en/digital-cultural-heritage (last accessed March 2021).

Architecture belongs to culture, not to civilization.

Alvar Aalto.

2. STATE OF THE ART

2.1. International initiatives

The Cultural Heritage sector is therefore moving fast in the direction of innovative research, increasingly connected to the issues and opportunities of digitization, resilience, and sustainability. Together with 'big' companies like Google or Microsoft, UNESCO, ICOMOS and ICCROM are just some of the most important institutions and organizations that are currently investing in these directions.

Cultural Heritage organizations are joining forces and embracing new technologies to preserve and exchange information about our fragile shared heritage. By digitizing their valuable collections and making the information available to conservation experts, museums, libraries, and archives are helping to protect our delicate heritage sites.

An example of a project is offered to us by Google with "Heritage on the Edge"[1], a tool created not only to travel virtually, but also to monitor the condition of some of the UNESCO sites at risk, mentioned in the previous chapter; or by World Heritage Journeys[2], an initiative by UNESCO, in collaboration with National Geographic and local heritage and tourism managers, to showcase World Heritage destinations and help travelers 'online' experience them in ways that protect and support their outstanding value and the local communities that sustain them. As part of UNESCO's *#ShareOurHeritage campaign*[3], UNESCO is working to promote access to culture – from World Heritage properties to living heritage practices – during this time of mass confinement. With the support of Google Arts & Culture[4], UNESCO is launching an interactive online exhibition featuring of World Heritage properties from across the globe.

The 3D technologies have numerous practical applications for Cultural Heritage, from cloud use to academic research, preservation, and conservation, with more innovations. For example, the European Commission, through the Horizon 2020 program, offers ongoing support for research and innovation in the field of Cultural Heritage.[5]

For instance, the ARCHES, DigiArt and EU-LAC-MUSEUMS projects have harnessed technologies such as 3D modeling and augmented reality. The EMOTIVE project exploited the potential of storytelling, offering tools to heritage professionals that allow them to create interactive experiences for the public. The Time Machine project developed a computing and digitization infrastructure that uses artificial intelligence and massive data mining to obtain and analyze the vast amount of data generated when digitizing museum and library archives. Technologies such as 3D scanning and modeling, augmented reality and virtual reality promise new ways of preserving and displaying Cultural Heritage for society to enjoy. In the face of today's complex challenges, the task seems more urgent than ever, since, in times of crisis, people need culture.[6]

---

[1] https://artsandculture.google.com/project/heritage-on-the-edge (last accessed March 2021).
[2] https://visitworldheritage.com/en/eu (last accessed March 2021).
[3] https://en.unesco.org/covid19/cultureresponse/ (last accessed March 2021).
[4] https://artsandculture.google.com/partner/unesco (last accessed March 2021).
[5] https://ec.europa.eu/programmes/horizon2020/en (last accessed March 2021).
[6] https://en.unesco.org/news/moments-crisis-people-need-culture/ (last accessed March 2021).

2.2. International organizations

International organizations such as: UNESCO - United Nations Educational, Scientific and Cultural Organization[1]; ICOMOS - International Council for Monuments and Sites[2]; ICCROM - International Centre for the Study of the Preservation and Restoration of Cultural Property[3]; ICOM - International Council of Museums[4]; ISPRS - International Society for Photogrammetry and Remote Sensing[5]; CIPA - Committee for Documentation of Cultural Heritage[6]; WMF - World Monuments Fund[7]; are among the most recognized organizations working in the Cultural Heritage sector (Fig. 11).

Fig. 11. International heritage organizations.

[1] UNESCO founded in London, in 1945. It seeks to build peace through international cooperation in Education, the Sciences and Culture. UNESCO's programs contribute to the achievement of the Sustainable Development Goals defined in Agenda 2030. https://en.unesco.org/

[2] ICOMOS is an international, non-governmental organization working for the conservation and protection of Cultural Heritage, the World's monuments, and sites. ICOMOS is the principal advisor of UNESCO in matters related to the conservation and protection of monuments and sites. As an international organization has a multidisciplinary network of professionals. https://www.icomos.org/

[3] ICCROM is an intergovernmental organization working in service to its Member States to promote the conservation of all forms of Cultural Heritage, in every region of the world. Those working on the front lines of heritage preservation, including scientists, conservators, museum curators, site managers, archivists, researchers, and archaeologists rely on ICCROM for its world-class initiatives in conservation training, information, research, cooperation, and advocacy. https://www.iccrom.org/

[4] ICOM is a non-governmental organization. Its international public service missions include fighting illicit traffic in cultural goods and promoting risk management and emergency preparedness to protect world Cultural Heritage in the event of natural or man-made disasters. https://icom.museum/es/

[5] ISPRS is an international, nongovernmental organization devoted to the development of international cooperation, in scientific and professional level, for promoting photogrammetry, remote sensing, and spatial information sciences, in terms of theory, methodology, and scientific techniques, tools and applications. https://www.isprs.org/

[6] CIPA is a dynamic international and multidisciplinary organization that keeps up with technology and ensures its usefulness for Cultural Heritage conservation, education, and dissemination. It was created in cooperation with ISPRS, to assist conservation professionals and experts with activities of Cultural Heritage recording and documentation. Originally, it was founded as the Comité International de la Photogrammétrie Architecturale. https://www.cipaheritagedocumentation.org/

[7] WMF is a private nonprofit organization founded in 1965 by individuals concerned about the accelerating destruction of important artistic treasures throughout the world. Now, over 50 years later, World Monuments Fund sponsors ongoing programs for the conservation of Cultural Heritage worldwide. https://www.wmf.org/

2.3. International strategies

Regarding strategies, especially the international ones, the recurring themes are the generation of networks of experts in the field of digitization of Cultural Heritage, focused on the design of ad hoc interventions.

Create and strengthen networks for community collaboration and engagement, use of digital technology and social media to promote best practices, focus on culture and creative projects and experiences that benefit local communities, encourage responsible behavior based on heritage values, improve innovative participatory and collaborative approaches; are some of the strategies most currently discussed by the international community.

Considering the need to react quickly and in an ever-changing environment, the proposals of international institutions to address the crisis are - fortunately - many. Such as the Manifesto signed in May 2020[1], on Cultural Heritage as a catalyst for Europe's future, the plan of digital recovery of Covid-19[2], the several reports by Europa Nostra as Challenges and Opportunities for Cultural Heritage in Covid-19, or by the European Cultural Foundation as Covid-19 Emergency Response in Europe in Arts, Culture, Cultural Heritage and Creative Sectors.

The several UNESCO proposals,[3] as the weekly Culture & Covid-19: Impact and Response Tracker publication that gives an overview of the rapidly changing situation, or the ResiliArt[4] movement to share good practices as a way of mobilizing the international community, support the creative sector and keep guaranteeing access to culture for all.

During this challenging time, artists and cultural professionals have been allowed to stay connected, despite the physical distance between each other through the several events, conferences, or webinars on the topic. Organized by CIPA, VAST, EGA, EUROMED, VASIG, CVRO, INNOVA, among others.

It emerges that the trend towards digitization has accelerated considerably during this year, a trend that is also reflected in many calls for funding from the European Union, such as the European Museum Collaboration and Innovation Space call[5] under the Horizon 2020 program. These advocacy strategies aim to ensure that Cultural Heritage is duly included in Europe's immediate response to the Covid-19 crisis as well as in the long-term recovery plans, including the European Union's recovery instrument 'Next Generation EU'.

[1] On 9 May 2020, on Europe Day, members of the European Heritage Alliance launched a Manifesto entitled 'Cultural Heritage: a powerful catalyst for the future of Europe'. Through this Manifesto, several hundreds of representatives of leading European and international heritage networks expressed the strong determination of the heritage world to contribute to Europe's immediate social and economic recovery, as well as to the longer-term advancement of the European project: https://www.europanostra.org/wp-content/uploads/2020/05/20200509_EUROPE-DAY-MANIFESTO.pdf

[2] McKinsey Recovery Digital, 14 May 2020. https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/the-covid-19-recovery-will-be-digital-a-plan-for-the-first-90-days (March 2021).

[3] UNESCO, 2020: Culture in crisis. Policy guide for a resilient creative sector.

[4] https://en.unesco.org/news/unesco-launches-resiliart-movement-artists-and-cultural-professionals-face-covid-19 (last accessed March 2021).

[5] https://ec.europa.eu/digital-single-market/ (last accessed March 2021).

Digital transition

Several cultural sites have demonstrated resilience and resistance by beginning to devise creative strategies to make their collections and exhibitions available to the public by exploiting the use of digital and virtual tools. At a time when people are looking to stay closer together while remaining physically distant, Cultural Heritage organizations have risen to the challenge. Europe already plays a leading role in digital Cultural Heritage and has the potential to move forward with new technologies such as artificial intelligence and machine learning based on humanistic and ethical principles.

Beyond the growing movement towards digital engagement in museums, this situation has been an opportunity to reconsider reaching visitors and potential audiences remotely. With the aim to promote new technologies and Cultural Heritage to the world, many institutions are supporting cultural strategies. At the educational level strategies such as “educational games, and interactive digital artworks”, are a resource to entertain the community and at the same time gain visibility.

The Covid-19 pandemic confirmed once more the importance of enabling the Cultural Heritage sector to seize the opportunities provided by digital technologies. According to the study of NEMO, the cultural sites have increased, started, or redirected resources to many online services during the pandemic.[1] While some of Cultural Heritage institutions have managed to use these technologies and turn the crisis into new opportunities for creative expression, more engagement and expansion of audiences, others have been heavily affected, with significant loss of revenue.

Museums indicated that social media activities proved most interesting to their online visitors. This was followed by educational materials, video content, online collection, and virtual tours. (Fig. 12). The use of social networks by those who manage a cultural site is a clear attempt to: promote events, try to reach new audiences, and try to increase the knowledge. Social platforms such as Facebook, Twitter, and Instagram, give the visitor the opportunity to access additional services and information, it is a way to allow all potential visitors who cannot physically go to the museum - currently all of us -, to visit any place through technological tools.

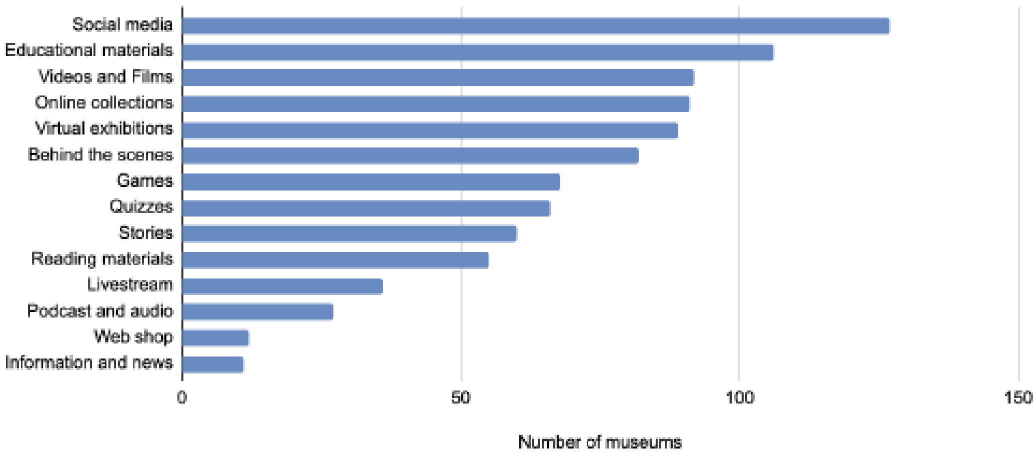


Fig. 12. User interest about Cultural Heritage online services. NEMO Report 2021.

[1] https://www.ne-mo.org/news/article/nemo/nemo-survey-on-museums-and-covid-19-increasing-online-activities-of-museums.html (last accessed March 2021).

One of the most popular strategies to come out of the coronavirus quarantine is *Tussen Kunst & Quarantaine* - which translates means “between art and quarantine”. This creative project invites people to recreate iconic works of art (from all periods) using objects they already have in their homes. And it posts them on a Dutch Instagram account.[1] It is a game, but it also brings people closer to art and culture.

Other interesting initiative was the hired robot to help enable would-be visitors to enjoy the exhibits of an art gallery during the coronavirus pandemic. The video-conferencing robot, with wheels and a camera, travels around the gallery under external control. People will be able to go on tours of the gallery overseen by guides. It was developed as an aid for people with disabilities but has been adapted for use in the gallery so people who cannot leave home during the lockdown can have art.[2]

New technologies and learning procedures are stretching the gap between the different stakeholders, and the international organizations, the academic and research community should come closer to redefine the relationship between the different players in the preservation workflow.[3]

For example, “Mona Lisa: Beyond the Glass” is a VR experience that reveals the latest scientific research on da Vinci’s artistic innovation and his painting techniques and processes through exceptional visualization in virtual reality, bringing them to life.[4]

Consequently, now it is the time for cultural sites to seize opportunities. Innovate to solve services to people and try to meet their needs, with projects that promote a digital, social, environmental, and sustainable union (Fig. 13).

Fig. 13. Visitor interest in online offers. NEMO Report 2021.[5]

[1] https://www.instagram.com/tussenkunstenquarantaine/ (last accessed March 2021).
[2] https://www.hastingscontemporary.org/exhibition/robot-tours/ (last accessed March 2021).
[3] This effort is in line with the 2015 UNESCO Recommendation concerning the Protection and Promotion of Museums and Collections, their diversity, and their Role in Society, which underlines the essential role of museums in the cultural field, both for education and for the development and well-being of populations, as well as the importance of information and communication technologies (ICTs).
[4] https://arts.vive.com/us/articles/projects/art-photography/mona_lisa_beyond_the_glass/ (last accessed March 2021).
[5] Follow-up survey on the impact of the Covid-19 pandemic on museums in Europe. Final Report, 2021. https://www.ne-mo.org/ (last accessed March 2021).

According to UNESCO Reports[1], the museum sector reacted very quickly to the Covid-19 crisis, developing its presence on the Internet in order to preserve connection with the community (Fig. 14).

Almost 70% of the museums increased their online presence since they were closed due to social distancing measures. After 3 weeks of closure to the public, already 80% of the museums had increased their online activity, reacting to the general increased visibility of Digital Cultural Heritage on the internet. Turning the threat of Covid-19 into an opportunity for greater support to documentary heritage, modern technology through internet and various apps has allowed for communication throughout the world while staying in lockdown, without physical contact. Some of the online platforms commonly used today for the 3D visualization of heritage, include references both scientific and popular as Google Arts & Culture, Sketchfab, CyArk, 3DHOP, among others.

The growth of cultural tourism and the technological advances in recent years have led to the development and implementation of several projects to investigate, preserve, interpret, and present various elements of architectural heritage using computer-based visualization.

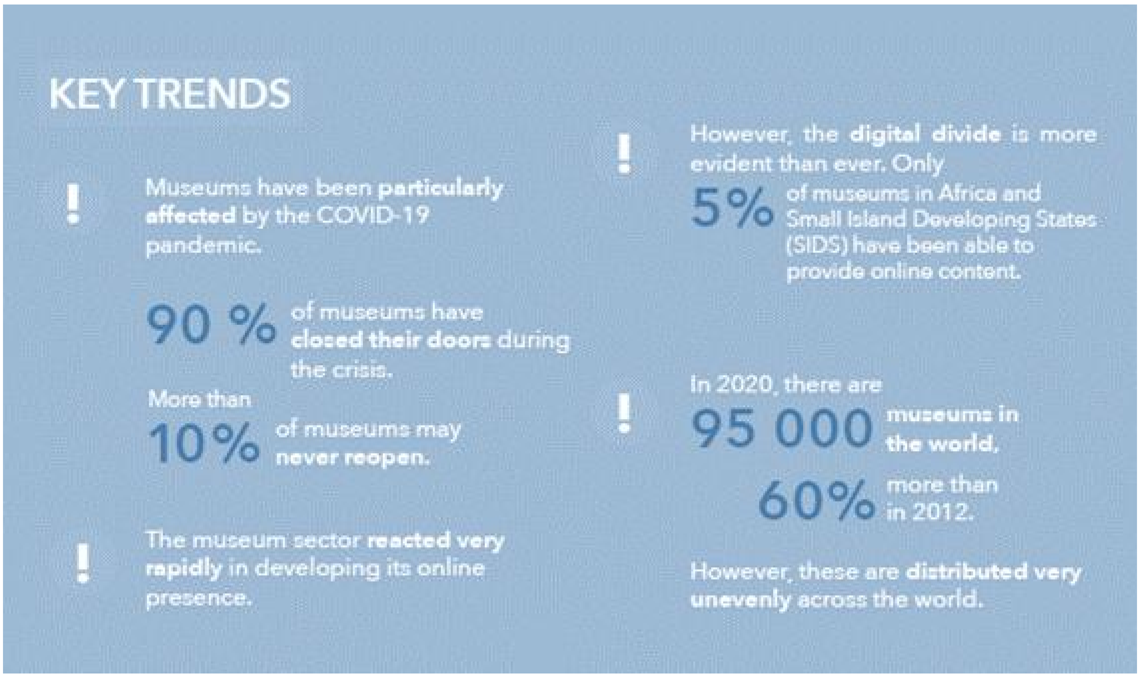


Fig. 14. Cultural Sector Key Trends 2020 of UNESCO.

[1] UNESCO launched a new Report on Museums Around the World in the Face of Covid-19, fruit of an international survey targeting museums, culture professionals and Member States. This report presents a first assessment of the impact of Covid-19 on the entire museum sector and provides new insights into the main trends in the world's museums, their reaction to the crisis, their resilience and the challenges of access to culture.

2.4. International charters

International communities, such as the United Nations (UN) and the European Union (EU) have recognized the importance of Digital Cultural Heritage practice, and through their fundamental charters, principles and treaties consolidate these values. In the Thesis are citated the most important references to promote the knowledge and to generate consciousness of the importance of digital conservation of Cultural Heritage.

1964 Venice | International Charter for the Conservation and Restoration of Monuments and Sites[1]

The Venice Charter aimed to safeguard important physical sites through conservation and restoration activities. "The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage" (Art. 2). "In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement, and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published" (Art. 16).

This implied that the activities of heritage recording, documentation, and information management, as defined hereafter should generally be integrated to a Conservation Management Process. This also implies that heritage recording should take place before, during and after any intervention to a resource if one wants to 'measure change' over time. The intention in conserving and restoring monuments is to safeguard them no less as works of art than as historical evidence. The Venice Charter principles have also been generally recognized as the primary policy guidelines for the assessment of Cultural Heritage sites on UNESCO's World Heritage List.

1972 Paris | Convention Concerning the Protection of the World Cultural and Natural Heritage[2]

The Paris Convention, in its Art. 1, referred to Cultural Heritages as monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science; groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science; sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.

[1] https://www.icomos.org/charters/venice_e.pdf (last accessed March 2021).
[2] https://whc.unesco.org/en/conventiontext/ (last accessed March 2021).

1996 Sofia | Principles for the Recording of Monuments, Groups of Buildings and Sites[1]

The Sofia Principles, also known as ICOMOS Principles manages to define a framework of recording principles in which Cultural Heritage is defined, conserved, and managed; purposefully ICOMOS organization is currently outlining proposals to update the document.

2003 Paris | Charter on the Preservation of Digital Heritage[2]

The Paris Charter advocated the protection and accessibility of the digital content of books, works of art and monuments as information for all. "Memory of the World Program aims to ensure the preservation and universal accessibility of the world's documentary heritage".

2009 London | Charter for the computer-based visualization of Cultural Heritage[3]

The London Charter is a set of recommendations which are relevant to the Cultural Heritage in general. The question of transparency of the various 3D visualization applications for Cultural Heritage is of high importance as a scientific discipline scientific and research-based method, computer-based visualization methods are now employed in a wide range of contexts to assist in the research, communication, and preservation of heritage (Fig. 15). The Charter defines principles for the use of computer-based visualization methods in relation to intellectual integrity, reliability, documentation, sustainability, and accessibility.

"The creation and dissemination of computer-based visualization should be planned in such a way as to ensure that maximum possible benefits are achieved for the study, understanding, interpretation, preservation and management of Cultural Heritage".

Fig. 15. Computer-based visualization methods for Smart Digital Heritage.[4]

[1] https://www.icomos.org/charters/archives-e.pdf (last accessed March 2021).
[2] https://unesdoc.unesco.org/ (last accessed March 2021).
[3] https://www.londoncharter.org/ (last accessed March 2021).
[4] http://smartheritage.com/ (last accessed March 2021).

2011 Seville | International Principles of Virtual Archaeology

The Seville Principles provided a framework for the creation of an authentic visualization of Cultural Heritage. Also, for the development and implementation of projects to investigate, preserve and interpret various elements of archaeological heritage using computer-based visualization. It defines principles based on interdisciplinary[1], purpose[2], complementary[3], authenticity[4], historical rigor[5], efficiency[6], scientific transparency[7], training and evaluation[8].

2015 Paris | Recommendation concerning the Preservation of, and Access to, Heritage Including in Digital Form

The Recommendation is arranged thematically under five topics: identification, preservation, access, policy measures and national and international cooperation. In light of these references, the underlying objective of heritage practices is to identify or create authentic content and preserve it, either in physical or digital form, as 'information accessible to all'[9]. Consequently, the processes employed to ensure authenticity and appropriate methods for preserving sites are key themes of these charters. The goal of a Digital Cultural Heritage practice must foster a means of making these sites public and accessible.

---

[1] "Any project involving the use of new technologies, linked to computer-based visualization in the field of archaeological heritage, whether for research, documentation, conservation or dissemination, must be supported by a team of professionals from different branches of knowledge". Given the complex nature of computer-based visualization of archaeological heritage, it cannot be addressed only by a single type of expert but needs the cooperation of a large number of specialists.

[2] "Any proposed computer-based visualization will always aim to improve aspects related to the research, conservation or dissemination of archaeological heritage. The overall aim of the project must be encompassed within one of these categories (research, conservation and/or dissemination). The category concerning dissemination includes both educational projects, whether formal or informal education, and recreational projects".

[3] "Computer-based visualization should not aspire to replace other methods and techniques employed for the comprehensive management of archaeological heritage (e.g., virtual restoration should not aspire to replace real restoration, just as virtual visits should not aspire to replace real visits)".

[4] "Computer-based visualization normally reconstructs or recreates historical buildings, artifacts and environments as we believe they were in the past. For that reason, it should always be possible to distinguish what is real, genuine, or authentic from what is not. In this sense, authenticity must be a permanent operational concept in any virtual archaeology project".

[5] "To achieve optimum levels of historical rigor and veracity, any form of computer-based visualization of the past must be supported by solid research, and historical and archaeological documentation".

[6] "The concept of efficiency applied to the field of virtual archaeology depends inexorably on achieving appropriate economic and technological sustainability. Using fewer resources to achieve steadily more and better results is the key to efficiency".

[7] "All computer-based visualization must be essentially transparent, i.e., testable by other researchers or professionals, since the validity, and therefore the scope, of the conclusions produced by such visualization will depend largely on the ability of others to confirm or refute the results obtained".

[8] "Virtual archaeology is a scientific discipline related to the comprehensive management of archaeological heritage that has its own specific language and techniques. Like any other academic discipline, it requires specific training and evaluation programs".

[9] Important aspect to consider is the European Union recommendation on digitization and online accessibility of cultural material and digital preservation (2011/711/EU). "To reinforce national strategies for the long-term preservation of digital material".

2.5. International measures

Based on the Convention Concerning the Protection of the World Cultural and Natural Heritage adopted by UNESCO in Paris in 1972, the international community is underlying many recommendations that emphasize the important aspects of heritage in relation to human rights and democracy. According to the Faro Convention, Cultural Heritage has a strong role in enhancing community cohesion[1], following a synthesis of international measures to support that role.

2011 | Recommendation on the Historic Urban Landscape adopted by UNESCO at its 36th session of the General Conference.

2015 | 2030 Agenda for Sustainable Development.

SDG 11.4 #CULTURE2030GOAL

‘protect and safeguard the world’s cultural and natural heritage’.

2015 | 1st UNESCO Global Report ‘Re|Shaping Cultural Policies’.

2017 | 2nd UNESCO Global Report ‘Re|Shaping Cultural Policies’.

2020 | Thematic Indicators for Culture in the Agenda for Sustainable Development.

These documents can be found in the UNESCO digital library[2] and they demonstrate the relevance of cultural and natural heritage for sustainable development.

According to the 2030 Agenda for Sustainable Development (Fig. 16), the cultural sector will move towards greater participation, changing the way cultural content and values are documented, transmitted, and perceived, in order to foster quality knowledge and sustainable tourism.

Fig. 16. Culture in Agenda for Sustainable Development.

[1] The Faro Convention is a unique convention about Cultural Heritage that emphasizes the value and potential of heritage as a resource for sustainable development and quality of life in a constantly evolving society. It emphasizes important aspects of heritage as they relate to human rights and democracy. It promotes a wider understanding of heritage and its relationship to communities and society and encourages citizens to recognize the importance of Cultural Heritage objects and sites through the meanings and values that these elements represent to them. https://www.coe.int/faro-action-plan

[2] https://unesdoc.unesco.org/ (last accessed March 2021).

Culture in Agenda 2030

The 2030 Agenda for Sustainable Development is a plan of action for people, planet and prosperity that was adopted in September 2015 by the international community and outlines a vision for a more sustainable future. The international community recognized the role of culture as a driver of sustainable development,[1] which can be addressed to contributes directly to bringing about economic and social benefits, as well as an enabler that contributes to the effectiveness of development interventions.

Heritage conservation can contribute significantly for developing sustainable communities, leading therefore to a sustainable future. The main components of sustainable communities are the economic, cultural, and social. It is important to highlight that the conservation of Cultural Heritage have several positive impacts on the long-term community sustainability. Some of them are the increased property values, the development of heritage tourism, the reuse of buildings and structures and the enhancement of the local economy (Trillo & Petti, 2016).

The cultural assets of cities, the heritage that gives meaning and identity to their inhabitants and the creative opportunities that enhance the vitality, livability and prosperity of cities must be strengthened.[2]

Building on an in-depth analysis of the multiple ways in which culture contributes to the economic, social, and environmental dimensions of development, the Thematic Indicators for Culture in the 2030 Agenda provide evidence of the culture's transformative role, making it more visible and tangible. In the Thesis has been approached the three following Sustainable Development Goals:[3]

GOAL 11: MAKE CITIES AND HUMAN SETTLEMENTS INCLUSIVE, SAFE, RESILIENT AND SUSTAINABLE.

11.4 - Strengthen efforts to protect and safeguard the world's cultural and natural heritage.

GOAL 4: ENSURE INCLUSIVE AND EQUITABLE QUALITY EDUCATION AND PROMOTE LIFE-LONG LEARNING OPPORTUNITIES FOR ALL.

4.7 - By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development.

GOAL 8: PROMOTE SUSTAINED, INCLUSIVE AND SUSTAINABLE ECONOMIC GROWTH, FULL AND PRODUCTIVE EMPLOYMENT AND DECENT WORK FOR ALL.

8.9 - By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products.

[1] Audrey Azoulay, Director-General of UNESCO.

[2] Irina Bokova, Former Director-General of UNESCO.

[3] https://sdgs.un.org/ (last accessed March 2021).

The academic community can afford this Goals to strengthen improving the quality of life through culture; for example, promoting initiatives such as Cultural Heritage for education as "an ideal way to give meaning to the future, by providing a better understanding of the past".[1]

In accordance, Europeana, an Europe's digital library, archive, and museum which was launched in 2008, is a single digital access point to 3D content on architecture, art, archeology, historic objects, and archival records that have been digitized across Europe. Its main objective is to make Cultural Heritage available online for everyone to enjoy, work or educate with. It makes it possible to create pedagogical scenarios with using the data of the platform. For example, it can be used to create the pedagogical scenario like the one entitled *'Travelling around the world and rescue our World Cultural Heritage'*,[2] where the students have the possibility to 'virtually travel' at the same time they are learning academic contents associated to these historical places. In fact, during the Covid-19 pandemic, through virtual classrooms and this type of remote learning, it was found an efficient solution to mitigate the impact of school closures.[3]

The problem for humanities researchers, teachers and creatives consists of the difficult of the access to trustworthy European Cultural Heritage content, mainly because of a lack of digitization and copyright issues.[4] The further development of these platforms will largely depend to the way the cultural institutions constantly feed it with content and make it visible to citizens.[5]

Indeed, historical 4D simulations can improve knowledge about history, and other subjects related. The data recorded by 3D recordings is widely used not only for preservation but also for academic, educational and tourism purposes.[6] CyArk, Open Heritage and Time Machine are just some of the organizations that publish digital archives on the website which associates 3D data acquired by a laser scanner and photogrammetry with related academic information.

The use of 3D data of Cultural Heritage can also be used in educational workshops such as, for example, the *'laboratorio a cielo aperto'*[7] promoted by the Department of Civil Engineering of the University of Salerno, where the direct objective was to broaden the knowledge of the students of the University of Salerno, providing them with the language, methods and infographic tools for the survey of architecture, as well as to deepen their knowledge of digital graphic techniques for the realization, visualization, presentation and communication of a graphic survey project. The workshop illustrated the most modern digital modeling techniques, from laser scanning to aerial photogrammetry; the activities included theoretical classes, practical campaign exercises and laboratory activities, where, for both students and tutors, some of the leading skills in 21st century education were developed, such as digital competence, teamwork, interest in collaboration and creativity, and commitment; making an approach to collaborative didactic experiences and promoting new learning methods. Creativity builds the resilience we need in times of crisis. It must be nurtured from the earliest

---

[1] Initiative adopted by the Committee of Ministers of the Council of Europe, 1998.

[2] Pedagogical Scenario proposal of Europeana Education, by the author. It demonstrated the importance of Cultural Heritage in the first year's education. https://urly.it/3c5h5 https://pro.europeana.eu/page/education (last accessed March 2021).

[3] While this is an option for some, it is out of reach for many students. The lack of access to computers and Internet at home, as well as a low level of computer-related skills, put many already marginalized students at a further disadvantage, and is an aspect that should be also consider.

[4] Europeana, Impact Insights 2017. https://pro.europeana.eu/files/Europeana_Professional/Publications/Impact%20insights%202017.pdf

[5] Again, important aspect to consider is the European Union recommendation on the digitization and online accessibility of cultural material and digital preservation (2011/711/EU). "To reinforce national strategies for the long-term preservation of digital material".

[6] For example, Cyark proposes 3D data for educational games https://cyark.org/monumentalideas/game

[7] https://www.facebook.com/events/1293293730772306/ (last accessed March 2021).

age to unlock imagination, awaken curiosity, and develop appreciation for the richness of human talent and diversity.

The main thing is the knowledge, reflection, and enhancement of Cultural Heritage so that young citizens become aware of its importance. The digital documentation of heritage sites went beyond simple digitization to include social and historical information, promoting the understanding of these places by people in the contexts in which they are found, and promoting an international impact, as these documents will be available to everyone, everywhere.

A series of strategies and techniques are to be used to make the communication of cultural content as engaging as possible and to capture the attention of different audiences. Hence the idea that Digital Storytelling, narration of cultural content with the support of digital tools, can be used to improve the enhancement and enjoyment of an asset. These stories, in fact, 'tell' stories about the museums themselves or about the objects and their culture through text, images, video, voice and sound effects, thus combining the value of traditional narrative with the potential of digital media. These are solutions that, by using additional information, succeed in making a monument accessible anytime and anywhere, and also in providing the necessary information to improve the experience for the public.

The use of VR is not restricted to the entertainment industry; it is used heavily in architectural visualization, education, medical training, military simulation, and more. VR is a trending subject in the Cultural Heritage industry. Community find the *immersiveness* very appealing. As we have seen in the previous chapters, the immersive techniques used in the field of the Cultural Heritage make the visit and the learning more effective.

The education industry has been looking for a more enjoyable and intuitive way of imparting knowledge onto students. For instance, seeing a VR walkthrough of the Pantheon in history class is exciting and memorable, since the experience is so engaging, for the student is much simpler to remember the information.[1] The potential benefits are enormous, both in terms of quality and efficiency. These tools increase the relationship between the user and the environment, involving all five senses and removing the limits of corporeality.

The relationship between game and learning is growing up with the new use of videogames. There are many video games, called serious games based on real scenarios, real monuments, and also refer to stories or real characters. This has brought advantages to the monuments themselves, being on a video game means being seen by many users, especially the younger ones, and means reaching the interest of a wider audience. Also, it is an advantage in terms of research in case of complete damage of the heritage. For example, *'Assasin's Creed II'*[2], serves as a support for the digitization of the paradigmatic case of Notre Dame (Fig. 17). All this makes the spectator more and more protagonist of the cultural experience, thus no longer being a passive spectator. The videogames are able to give artistic currents, authors and their 3D style and movement.

Cultural sites should try to offer unique and engaging experiences, so that the online site becomes more than just a visit and not a substitute for it. A virtual museum, or a digitized architecture can be 'visited' by anyone, anywhere. It is, therefore, a way to shorten geographical distances, everyone can see everything.

The use of technologies to communicate what culture has to say, encouraging community participation, will allow communities to engage with their own heritage, generate meaning around it and, in this way, share and preserve it for future generations. Furthermore, conservation and preservation of Cultural Heritage cannot be considered without recording and

[1] According to Edgar Dale (1969) people remember 10% of what we read, 20% of what we hear, 30% of what we see, 50% of what we see and hear and 80% of what we experience.
[2] https://www.ubisoft.com/es-es/game/assassins-creed (last accessed March 2021).

documentation. According to the UNESCO recommendations, the world's documentary heritage is of global importance and responsibility to all, and should be fully preserved and protected, with due respect and recognition of cultural values and practicalities.[1]

In the academic community, a scientific debate on the virtual reconstruction of heritage is underway. Numerous papers and projects aim to create effective guidelines and best practices in the field of scientific visualization of the past, coinciding in a common database of 3D content stored according to FAIR principles, findable, accessible, interoperable, and reusable.[2] These principles will be pursued in the methodology of the Thesis.

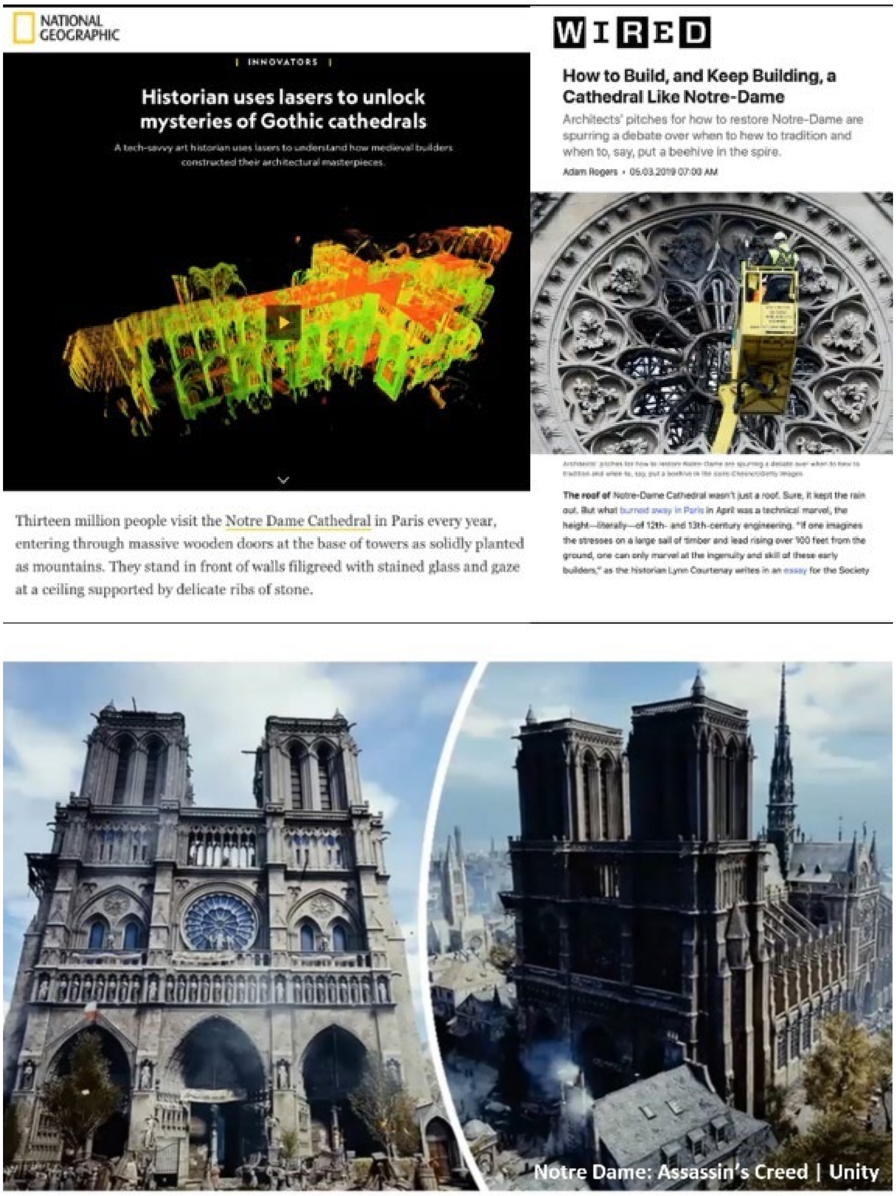


Fig. 17. An example of the importance of Cultural Heritage digitization.

[1] UNESCO Recommendation concerning the preservation of, and access to, documentary heritage including in digital form. http://portal.unesco.org/ (last accessed March 2021).

[2] https://www.go-fair.org/ (last accessed March 2021).

2.6. International scientific research

Many projects concerning the protection, conservation, and dissemination of Cultural Heritage are being carried out around the world due to its growing interest as a driving force of sustainability development.

The existence of reliable, digital 3D models that allow the planning and management of historical architectures in a remote and decentralized way is currently, more than ever, a growing necessity. There are many processes and software tools to perform the modeling and complete 3D documentation of the Cultural Heritage.

The UNESCO recommendations of the international guidelines that are relevant to 3D heritage digital conservation are condensed into nine key criteria (Statham, 2019), multidisciplinary teams, objective-based methodology and tools, careful documentation, type of reconstruction and level of certainty, authenticity, alternative hypotheses, multiple historical periods, respectful use of heritage, and community engagement.

Every historical building has its own architectural identity due to its singular past and historical changes over time. Architectural heritage is characterized by very complex and irregular shapes. Documenting the surviving evidence of cultural -tangible- heritage has traditionally been the starting point of any research in the fields of the Humanities and Social Sciences such as archaeology, art history, architectural history, and many other disciplines of Cultural Heritage.

3D digital survey techniques, such as photogrammetry and laser scanning, are by far the most studied and rapidly developing tools in the heritage buildings data capturing process (Cabrera Revuelta et al., 2021; Khalil & Stravoravdis, 2019). Photogrammetry, for example, is a well-known technique for interdisciplinary operators from a variety of fields of application (Barba et al., 2019; Sánchez Rivera et al., 2017). It becomes increasingly important since methods like structure from motion (SFM) are available in cost-effective software solutions.

In the last decade, due to the evolution of computer vision algorithms and modern computing techniques, photogrammetric image processing has experienced a significant increase in its applications, now taking less time and being mostly automated. An efficient information management strategy should take into consideration three main concepts: segmentation, structuring the hierarchical relationships and semantic enrichment (Grilli & Remondino, 2019). There are multiple studies related to the automated segmentation of point cloud, mainly driven by specific needs provided by the field of heritage documentation and preservation.

Moreover, the advances of the algorithm image-based is allowing the emergence of other approaches such as videogrammetry (Torresani & Remondino, 2019), an innovative method that can be a valuable source for 3D reconstruction and documentation in the heritage community, especially in emergency scenarios of Cultural Heritage at risk.

Furthermore, laser scanner, terrestrial (TLS) or mobile (MLS), are improving their performance and lowering their costs. Mobile and handheld laser scanning systems were also developed to speed up the acquisition phase using Simultaneous Localization and Mapping (SLAM) technology. Even if the accuracy of MLS is generally worse with respect to the one of TLS, their higher productivity is an important advantage that allowed such a platform to gain popularity. Regarding emergency contexts, a dynamic solution of recording is experienced in (Sammartano & Spanò, 2018) where some operative replies are provided to evaluate the effectiveness and the critical issues of the SLAM-based mobile mapping system (MMS) for the final purpose of Cultural Heritage conservation.

Stylianidis & Remondino (2016) agree with the recording at the first stage of cultural conservation but also point out that 3D modeling of heritage is one important step, and that visualization, VR applications, 3D repositories and catalogues, and Web GIS, among others, open further opportunities to improve the management of heritage buildings.

Modeling tools have changed the way technicians interact with the built environment. In addition to the remarkable increase in detail, accuracy and efficiency, the use of these tools in heritage and conservation has also increased access to Cultural Heritage (Grayburn et al., 2019).

The AEC sector has adopted the building information modeling (BIM) standard over the last few decades due to the progress that has been made in its qualities and capabilities (Shehata & Rodrigues, 2019). Regarding our field of application, historic building information modeling (HBIM), is an emerging technology that enables users to understand, interpret, document, and virtually reconstruct the Cultural Heritage. Currently it has become a widely researched topic.

HBIM was developed in the last 12 years (Murphy et al., 2009) like a new prototype-system of BIM, a modeling of historic structures as parametric objects in a repository database. These objects can be collected and modelled using a reverse engineering process, creating full 2D and 3D models including details behind the object's surface, concerning its methods of construction and material makeup. Information is taken on the base of 3D reality-based data from point clouds, by automatic or semi-automatic recognition (Murphy et al., 2017). The HBIM, is defined by the scientific literature as the most interesting method to define a semantic aware 3D reconstruction of historical elements, regardless the needs, the aims and the uses of this 3D model based on parametric approach (Rahaman et al., 2019).

To create a detailed HBIM model of the heritage is a great opportunity, not only in terms of knowledge enrichment, but also in terms of production of a project that could be as close as possible to the real condition of the building, developing ad hoc solutions. An instrument that can be used to support the diagnostic analysis, the design project, and the restoration itself. HBIM methodology allows providing not only a visual description of the monument but also the implementation of a smart database of semantic information concerning its conditions, materials, and history (Scianna et al., 2014).

The possibility of creating an accurate survey based on digital techniques of laser scanning or photogrammetric, allows to deepen the 'Scan-to-BIM' process. The different approaches developed generally subdivide the process into four specific steps: scan preprocessing, segmentation of the point cloud, classification of detected objects and final reconstruction of the BIM model. Consequently, starting from survey information through the import of point clouds into the management system allows a parametric digital representation of an existing building or structure. Classification is generally performed by taking into consideration a set of features (e.g., geometrical) and contextual information (e.g., nearby relationship). Currently Machine Learning applications for the classification and segmentation of point clouds through primitives are being implemented (Grilli & Remondino, 2019; Matrone et al., 2020).

Additional challenges are present in the processing of historic buildings: irregular geometry, non-homogeneous materials, variable morphology, not documented changes, damage and various stages of construction.

Due to the irregular and non-standardized elements of HBIM objects, the possibility of creating extensive parametric object libraries, as well as, automated object recognition tools, represents a major challenge that more research is needed to address (Murphy et al., 2017).

To overcome these challenges, Garagnani & Manferdini (2013) propose a parametric modeling of complex geometries using a reference point cloud by using the GreenSpider plugin for Revit. Previtali & Banfi (2018) propose different workflows for increasing the automation in HBIM generation from a point cloud with the implementation of different plugins for Revit. Also Banfi (2019) introduces a new definition, grades of generation GOG for heritage buildings. An application to reduce the generative time and cost of HBIM process. By the conversion of the traditional techniques on the generation of 'unique' digital models able to connect different type of information, through the GOG. Abbate et al. (2020) investigates the HBIM parametric modelling of a parabolic concrete vault from TLS, MLS & UAV photogrammetry integrated point cloud for the structural analysis based on finite elements.

Open research topics are big survey datasets management (Wujanz et al., 2018), multi-resolution surveys (Banfi, 2019; Girelli et al., 2017), and automatic point cloud segmentation (Grilli & Remondino, 2019).

Conservation of architectural heritage is a process of knowledge, maintenance, management, and enhancement aimed at preserving data of complex systems, such as historical buildings, which are the result of historical events, different architectural influences, changes in ownership, and transformations over time. Keeping alive these historical remains, respects the past and the value acquired over centuries. Osello et al. (2018) propose to use HBIM to manage maintenance activities throughout the life cycle of historic buildings. Parisi et al. (2019) propose to use HBIM for historic documentation with semantic approach. According to this, the BIM methodology can be considered as a bridge between the archive documentation and the digital model, an effective tool semantically oriented data repository.

It can be used for restoration purposes. Conti et al. (2020) experience the HBIM methodology of the architectural heritage in terms of not only gathering information but as a design tool to be used in a maintenance and restoration project. Chiabrando et al. (2017) studied the feasibility of modeling the complex geometry of historic architecture using BIM from point clouds, and to promote knowledge and management of Cultural Heritage. Lo Turco et al. (2017) explore the 3D modeling of decays in the BIM platform ensures to enrich the related database with graphic, geometric, and alphanumeric data that can be effectively used to design and manage future interventions with the capability to associate new parameters that describe both the state of conservation of the materials and the detailed description of interventions needed to restore the building.

The development of BIM technology for the HBIM area also gives its general contributions such as energy analysis, economic analysis up to multi-thematic analysis within sustainability. In addition, can be used for touristic management purposes, such as historical heritage information dissemination for culture and tourism development (Salvador García et al., 2018). Barazzetti et al. (2015) have developed a way for uploading HBIM models to the cloud for remotely accessing the information from mobile devices. The work aims at demonstrating that a complex HBIM can be managed in portable devices to extract useful information not only for expert operators, but also towards a wider user community interested in cultural tourism. Angulo-Fornos & Castellano-Román (2020) explore HBIM models generation for managing heritage information, oriented to preventive conservation of assets of cultural interest. Bruno & Roncella (2019) use HBIM as a methodology to support documentation, management, and planned conservation of historic buildings, with particular focus on non-geometric information: organizing and coordinating storage and management of historical data.

HBIM can be also used to convey the history of built heritage for education purposes (Previtali et al., 2020) with the creation of HBIM library to explain and teach structural systems used in construction and decoration (Brumana et al., 2017). Yang et al. (2019) present a BIM game prototype for integrating BIM models and interactive games with an intuitive interface to enhance architectural education. Their research is focused on the workflow, from the study of built heritage to the HBIM, which allows users to interact with it in an immersive virtual tour, immersive and virtual.

Stober et al. (2018) apply HBIM as a research tool for historical building assessment. The results point to the advantages of the model building approach for valorization and interpretation of constructive changes over time. The proposed approach uses digitalized sources, point clouds, to provide a rich support for the 3D modelling process while other techniques are led according to problem identification.

According to Osello et al. (2018) HBIM is a new opportunity to preserve architectural heritage, their research show a direct relation between a historical digital model, finalized to the management of architectural and system components, and visualization tools. To improve the visualization of the data contained in the information models, they combine HBIM models with immersive visualization techniques such as virtual reality (VR) and augmented reality (AR).

The semantically enriched model can be transferred into a WEB based game engine platform. The proposed design in the final figure below combines HBIM with Game Engine tools and technologies as an active repository of associated knowledge and data.

Therefore, the advantage of using HBIM methodology lies with the optimization of processing time, maintaining a sufficient accuracy in relation to the goals.

Modeling and visualization tools offer more than a replica of the real context; it allows virtual hypothetical reconstructions based on past interpretations that can be developed in different periods of times and can be related or overlaid with the archaeological surviving evidence. Anyhow, the 3D reconstructions of the present and past require a reality-based acquisition and modeling, connected with spatial and geographical data (Fassi et al., 2016). The direct fruition of the virtual model through fully immersive strategies could open the path for an innovative development in the field of architectonic maintenance, improving our understanding of the spaces and allowing to immediately georeference the information.

Advanced digital tools can help the process of preservation, also fostering a participatory process connecting diverse experts with various skills and educational backgrounds, and then empowering the maintenance activities of the heritage sites (Liu et al., 2020). This can be performed through the creation of a tool for conservation and monitoring activities of Cultural Heritage by a database collaborating with local institutions and experts, following the real needs of the site (Tommasi et al., 2020).

Current technological advancements offer many ways of enhancing disabled people access to Cultural Heritage environments. A new generation of social computing technologies and systems is changing the way in which we access Cultural Heritage, facilitating the inclusion of socially isolated groups of people.

State of the art solutions in voice interaction, scanning, touch and haptics interaction, gestures, head pose interaction, sign language, persuasive and affective interaction, serious games, and augmented reality offer numerous possibilities for the development of inclusive social computing applications, particularly in the domain of Cultural Heritage (Kosmas et al., 2020).

Also gamification has been applied to several applications domains including Cultural Heritage and it has a popular approach to increase the entertainment and thus the motivation factor of users (Papagiannakis et al., 2018). Serious games are designed for a wide general audience and then require a user-friendly interface customized to learning objectives, is evident the importance of these strategies for their ability to fulfil cognitive learning outcomes and motivate users. Guidazzoli et al. (2016) have presented a virtual reconstruction of archaeology, where the scenes can be updated and reused to tell constantly new stories. For heritage education purposes (Luigini & Basso, 2021), or to give 'Life History' for the memory of Heritage in Virtual Environments (Walters, 2020). The web has a potential to bring Cultural Heritage on the screen of any enthusiast.

In conclusion, the new technologies applied on Cultural Heritage, reopen new opportunities and challenges, favoring lines of research that portend interesting developments in the field of surveying, modeling, and conservation of historic architecture. Keeping in mind that virtual models will never replace the physical visit, but they can be a complement. It will certainly increase the understanding of the Cultural Heritage by the visitor as well as support studies and scientific analyses.

Motivation of the Research

"The world we have is the result of our own action. We have the capacity, if we wish, to create another world".[1]

In difficult times, Cultural Heritage plays, and will continue to play, an essential role in the physical and mental well-being of each individual and societies as a whole. Well-being is a holistic concept that encompasses the emotional, social, cultural, spiritual, and economic needs that enable individuals to realize their full potential and participate in society to their fullest capacity. Hence, investing in Cultural Heritage means investing in well-being, in public health, and improving people's quality of life.

In these times of restrictions, how can we help people continue to access culture?

Digital technologies have the potential to enable citizens to actively engage and interact directly with Cultural Heritage. Through new resources for the documentation, promotion, and preservation of Cultural Heritage with the application of survey techniques, digital modeling, and immersive experiences. With the creation of 3D models that advance on the concepts of sustainability and transcendence of Cultural Heritage, it is possible to move towards greater cultural participation. Therefore, through effective communication that does not simply replicate reality, but adds other values, access to information that promotes new frontiers towards the fruition of Cultural Heritage will be achieved.

How can digital technologies serve as a basis for education, research, and management of cultural sites?

The integration of information, communication and visualization tools for Cultural Heritage promotes culture-based creativity, historical learning, cultural diversity, and social cohesion. From a scientific point of view, with technologies such as VR and AR, the space of a room will no longer be a limit: VR allows the world to be explored virtually, while AR brings abstract concepts to life. This will allow researchers to immerse themselves in 360° scenes populated by 3D objects, breaking down all physical barriers, becoming an effective interpretation tool. From technology transfer, from point cloud to BIM models, which are no longer just containers of geometric information, but add qualitative and quantitative information, the management and conservation of cultural sites will be more efficient.

How can we help prevent the risk of loss of cultural memory?

We have seen many Cultural Heritage industries act very efficiently on most of the opportunities offered by digital technologies during the crisis. In particular, the use of virtual tours in various innovative formats, such as 3D models, 360° videos, or virtual reality experiences, or live and virtual events and activities. Digitization can contribute to the conservation of Cultural Heritage. The goal of digital conservation is to study, record, maintain and communicate the important cultural assets of a society and thus preserve them for future generations. These requirements from society for digital fruition of culture, may be the key tool to change the way in which the cultural content and values are perceived. The international community is currently working hard to try to give answers to these social requests.

[1] Therese NDri Assie-Lumumba, UNESCO.

A crisis highlights all our fault lines, we can pretend that we have nothing to learn, or we can take this opportunity to own the truth and make a better future for ourselves and others.

Brené Brown.

3. CONTRIBUTION

With the evolution of digital technologies, as we have seen in the preceding chapter, today's evolving digital technologies offer increasingly innovative communication systems that have the potential to revolutionize the way people experience and use cultural sites.

The user can currently experience the heritage from a virtually reconstructed environment. Today's society is facing a digital generation: people can barely imagine a world without Internet, smartphones, and social networks. This research, will concentrate mainly on the new generations, a society that today is stimulated almost exclusively through emotions and through experiences, multimedia, interactive, immersive, etc.

To delve deeper into this generational change and better understand the target to which this Thesis will refer, according to Balaguer (2018), generations that used to be defined by major historical or social events, today are delineated by the use of certain technology. Mobile technology, social networks and the use of the internet have become increasingly important for young people in the 21st century. Young people use the internet as a tool to acquire social skills and learn about any kind of topic that interests them. The increasing use of mobile technology has led people to spend more time on their smartphones and social networks, which they use to stay globally connected. Therefore, the development of online relationships is a new generational standard, mainly increased by the context in which we are living, where the coronavirus crisis has imposed the trend of 'socially close' although 'physically distant'.

In order to manage relations with the media and conduct the research directly towards the identified target, considering the current situation, strategies of digitization, reconstruction, modeling, and visualization of Cultural Heritage will be used in this thesis. The aim is to offer a new experience on the fruition of Cultural Heritage, an initiative that promotes awareness and a sense of belonging to the heritage by society, even at a remote distance. This would create new user experiences, based on immersions, sensations, and emotions.

New ways of disseminating heritage to the public will be experimented, promoting meaningful experiences for a wide audience, for researchers as well as technology enthusiasts. The use of digital tools in Cultural Heritage has a variety of potential uses. For example, the creation of a 3D model of an existing heritage object, building or site 'virtualizes' the monument, and makes it easier for a user to visualize and interact with it in different ways and with different degrees of immersion.

An efficient use of digital tools derives from a codified methodological process, which considers the integration between traditional and innovative methods. The Thesis will experiment a methodology that integrates instruments, techniques, and operators, through a multidisciplinary approach, to promote an extended fruition of Cultural Heritage. The methodology arises from the need to document heritage through the integration of innovative techniques of survey and three-dimensional reconstruction, being fundamental tools for the knowledge of Cultural Heritage.

In addition, the use of these tools provides archaeologists, architects, engineers, academics, and other professionals in the field of Cultural Heritage with an indispensable instrument for understanding and analyzing the complexity of the data that constitute an architectural object. The quantity and quality of the graphic results that can be obtained facilitate historical interpretations and communicate them in an easily understandable way. History is an instrument that helps us to know the past, understand the present and predict the future, and technological tools have brought many innovations to traditional research methods.

Architecture should speak of its time and place but yearn for timelessness.

Frank Gehry.

4. OBJECTIVES

The main objective is to promote a digital heritage that is more accessible and understandable for different types of users, without losing the scientific rigor that characterizes the object. Hence, the idea is to generate technical-scientific information in an HBIM environment, which, if necessary, can also play a social role; an operation carried out on the innovative integration of diversified survey tools for a precise, accurate and complete documentation.

The need for rigorous documentation of the current state of the heritage is summarized by the words of Mannoni (2000) “it is not possible to make a good archaeology, so with good critical reasoning, without a good archaeography, or a good objective description of the starting data, because you cannot objectively have in hand everything you want to compare. Archaeography alone is not useful, but neither is archaeology alone, that is without its right arm, but more and more often, as we have seen, the archaeological ‘brain’ cannot do without its left arm, which is archaeometry”. The motivation of the Thesis arises, therefore, from the need for graphic representations of a more and more rigorous technical nature, but at the same time more effective even for a non-technical public. All this in order to offer a codification of the Cultural Heritage itself: in fact, architecture becomes heritage only when it is understood, accepted, and recognized as such by the community of those places.

Consequently, the specific objectives can be summarized as follows:

To contribute to the conservation of Cultural Heritage through accurate three-dimensional digital documentation. Providing critical graphic representations and accurate models for its management.

To provide a heritage database for future generations. Producing an accurate record of Cultural Heritage and making the data available to the academic community in the future.

To develop graphic material that promotes and guarantees the conservation of the heritage. That limits the effects of time and prevents, in relation to the nature of the object, the loss of its characteristics of authenticity.

To improve accessibility, visibility, and recognition of the value of Cultural Heritage by developing new forms of cultural experiences. Applying immersive visualization technologies.

To attract a wider public to take an interest in Cultural Heritage. With communication and visualization tools with a user-centered approach.

The contribution of the academic research within the scope of this Thesis is reflected in the definition of a digitization and valorization strategy, therefore, also with possible social derivations. With *CAME* methodology based on integrated survey and HBIM methodology, focused on the object. To guarantee a technical data useful for the management and for the appropriation of the digitized heritage by its community.

A complete record of an object defined as Cultural Heritage, containing all the appropriate data and information, can not only support any virtual or physical reconstruction process, but is also capable of transferring knowledge to future generations. Documentation is an irreplaceable connection for the whole process of restoration, conservation, or preservation of Cultural Heritage. It can help prevent Cultural Heritage from being damaged or forgotten, and it serves to communicate and raise consciousness, not only among conservation experts and professionals, but also among the general public, laying the foundations for a new form of preservation and enjoyment of Cultural Heritage.

The present is only understandable through the past, with which it forms a living continuity; and the past is always grasped from our own partial viewpoint within the present.

Terry Eagleton.

5. METHODOLOGY

5.1. CAME - A digital representation of the physical world

Never forget where you CAME from

This Thesis strive to develop an integrated methodology that facilitates the codification of new guidelines for the conservation of Cultural Heritage, from the cataloging of the same, to the digitization, through applied survey and modeling technologies, using immersive visualization techniques, not only for informative and educational purposes, but to promote its fruition, conservation, and transmission to future generations (Fig. 18).

CAME, which stands for Collection, Acquisition, Modeling and Enhancement, is an integrated methodology to provide effective infographic documentation for the expanded fruition of Cultural Heritage. The methodology is schematized according to a Cartesian coordinate system - purely for graphic purposes - that goes from public to technical on the horizontal axis, and from real to virtual on the vertical axis (Fig. 19). An object centered methodological proposal, focused on interdisciplinarity, collaboration and interoperability between different software environments (Figs. 20,21).

CAME is organized in four main phases:

Collection: The first phase is related to the knowledge of the Cultural Heritage object under investigation. It involves the planning and organization to gather data and information. It includes the analysis, interpretation, and hypothesis of all the physical, technical, historical, semantic, and descriptive characteristics.

Acquisition: The second phase is the geometric investigation, the survey with advanced technologies of data capture, processing, integration, and optimization of datasets. The result of this phase is, among others, a 3D point cloud of the object of study.

Modeling: The third phase is the geometric, technical, and semantic reconstruction of the object of study. In this way, all the information of the object will be stored in a synchronized and collaborative platform. This has huge advantages for the management of information about the Cultural Heritage.

Enhancement: The fourth phase is oriented to the dissemination of all the collected and processed data and information. The result of this phase becomes a tool for the promotion of the future activities, uses and expanded fruition.

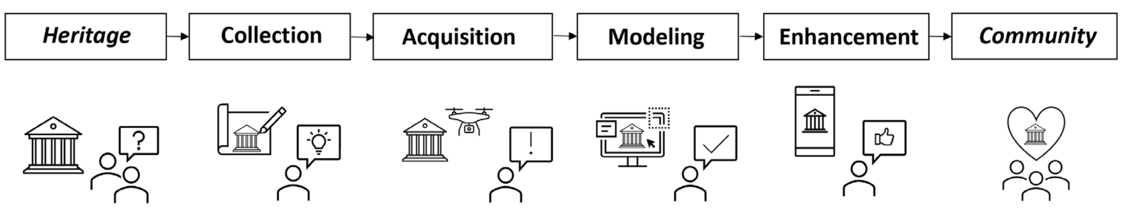


Fig. 18. CAME - Methodology mission.

CAME - Mission

The conservation of Cultural Heritage consists of maintaining the original state of objects, architecture, or historical sites; to preserve their authenticity, their materials, their characteristics, their values. Documenting heritage is a fundamental part of the process for its protection and sustainable management.

The comprehensive digital acquisition of Cultural Heritage is a complex and multidimensional process. It depends largely on the nature of the object of acquisition, as well as the purpose of its study. The whole process involves case analysis, 3D digitization, digital data processing, documentation, representation, and dissemination.

In addition to this four-stage pipeline, the whole process is connected three W and one H. *What is CAME?* A methodological proposal for the expanded fruition of Cultural Heritage; *Who will use CAME?* An interdisciplinary team, according to the international guidelines for Cultural Heritage protection; *Why will be used CAME?* To follow the purpose of digital conservation of Cultural Heritage; *How CAME will be used?* Following step by step the main phases and using specific techniques and soft and hard skills.

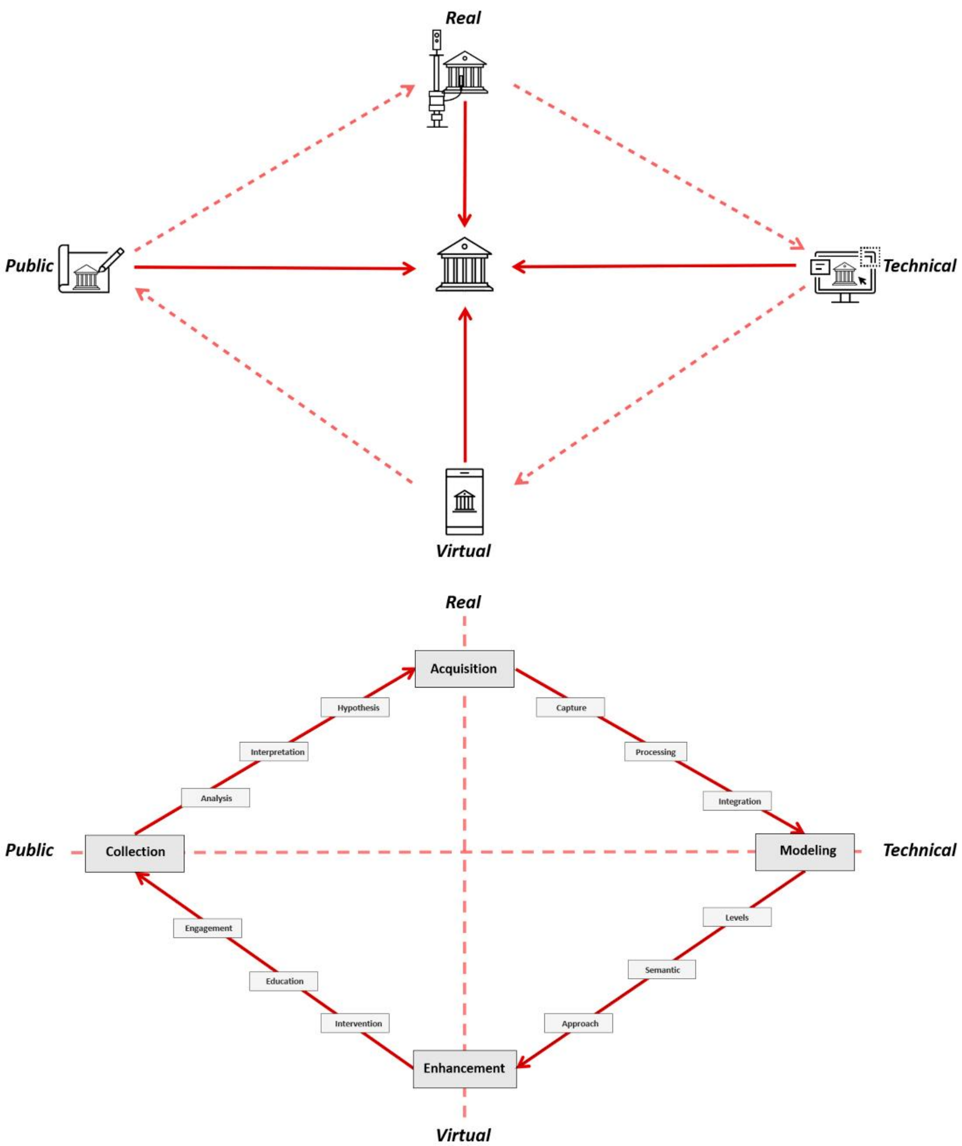


Fig. 19. CAME - Methodology step by step.

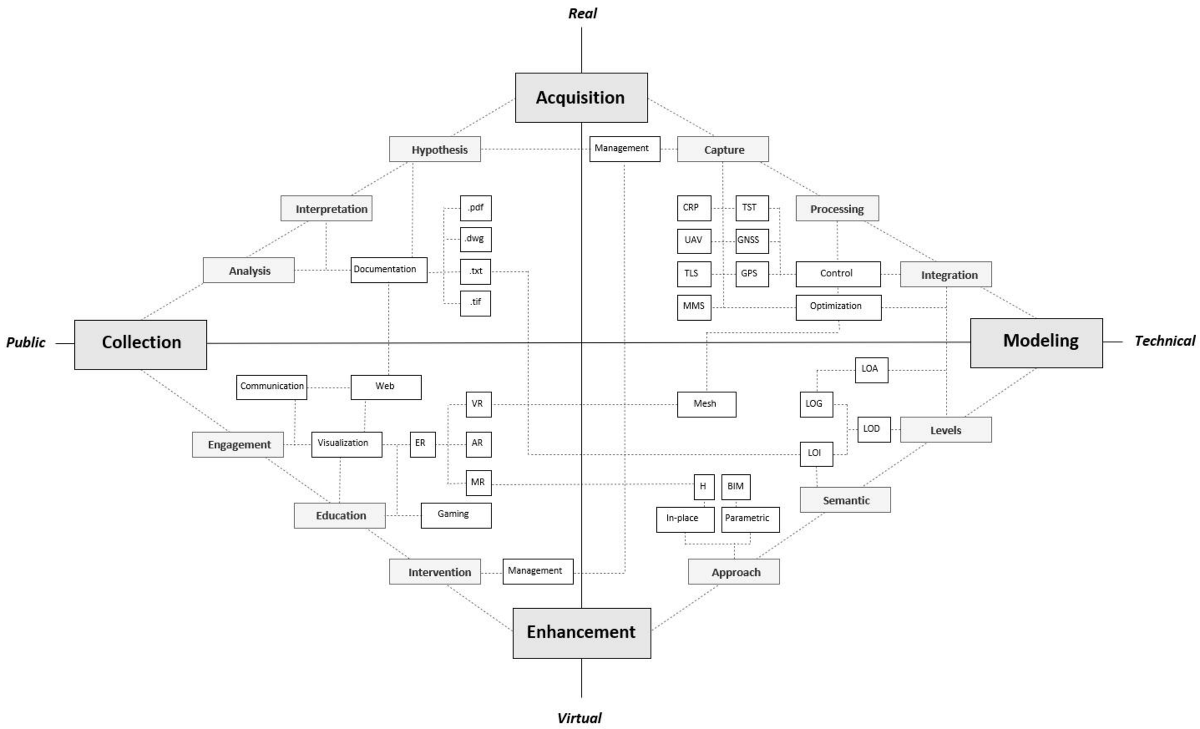


Fig. 20. CAME - Methodology scheme.

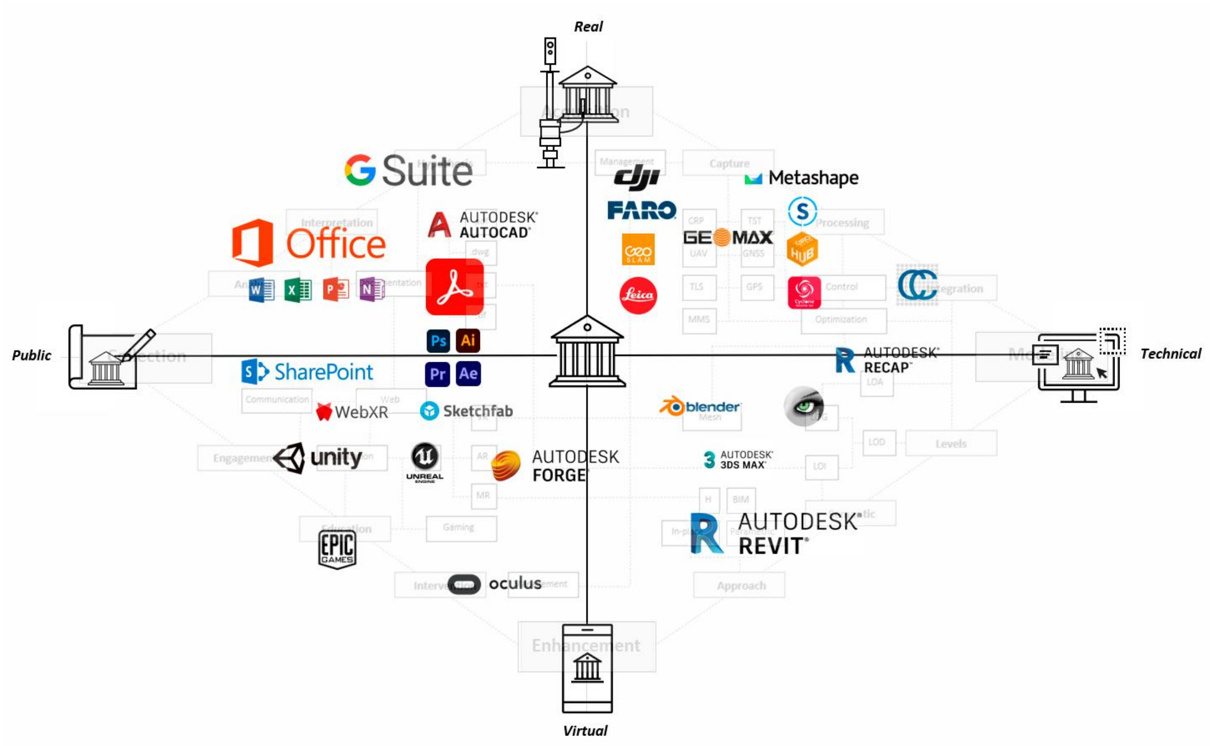


Fig. 21. CAME - Methodology software interoperability.

5.1.1. Collection

The first phase is related to the knowledge of the Cultural Heritage object under investigation. It involves the planning and organization to gather data and information. It includes the analysis, interpretation, and hypothesis of all the physical, technical, historical, semantic, and descriptive characteristics.

It lies with the process of understanding of building's characteristics and their appropriate documentation, through the analysis, selection, synthesis, and representation of the architectural characteristics. This phase is characterized by the succession of the following steps: a preliminary study and analysis of all the gather information, then the interpretation and hypothesis that search to give answer to: what does the monument try to tell us? It, therefore, tries to give answer through an analytic and interpretative approach.

Every historical object of study is an organic element that is transformed over time according to the desires and needs of society. It adapts to social, economic, and cultural conditions over time. Therefore, it needs to be understood in this sense.

Original designs, old photographs, notarial archives, documents, cadastral certificates, and any other documentation deemed necessary to highlight all the elements that have determined the configuration of the building in its original configuration will be collected. The first step of CAME methodology, based on data collection, provided the basis for constructing knowledge. This step has proven to be essential to have meaningful information to guide future decisions on a specific case study.

The study of architecture is carried out through the integration of multiple factors that contribute, to a greater or lesser extent, to the development of the models necessary for a comprehensive understanding of the architectural object.

This leads to the next phase, the acquisition phase, which constitutes a phase of the deep cognitive process of the object of study that acquires an ever-greater dimension with the evolution of information technologies and with the development of specialized instruments (Fig. 22). All of this with the aim to be a tool for an increasingly inclusive and accessible Cultural Heritage environment for those who do not have access to or are not sufficiently included in Cultural Heritage experiences.

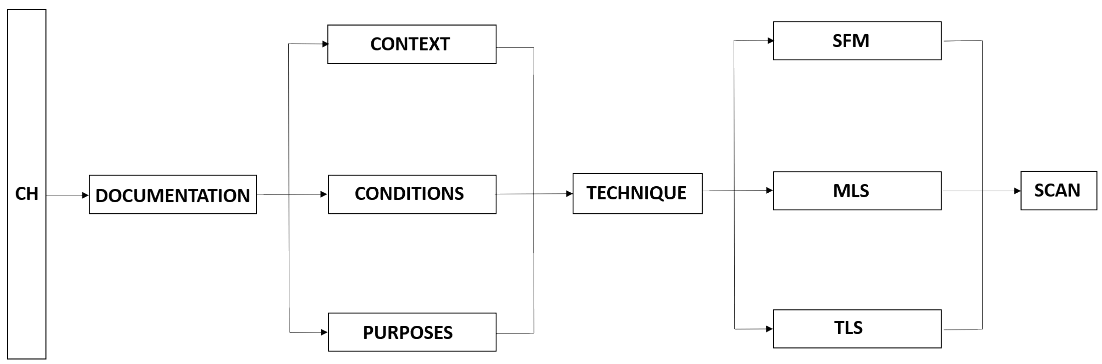


Fig. 22. Outline of the former steps of the CAME methodology.

5.1.2. Acquisition

The second phase is related to the geometric investigation, the 3D survey with advanced technologies of data capture, processing, integration, and optimization of datasets. The result of this phase is, among others, a 3D point cloud of the object of study.

The acquisition phase provides us with the metric, geometric, constructive, and spatial characteristics. With the objective of arriving to a deep knowledge of the Cultural Heritage, of its history, this second phase seeks to give answer to: how can technology generate new ideas? The survey is considered a documentation susceptible to new interpretations.

The survey operation cannot be reduced to the acquisition of purely geometric data. It determines a 3D documentation where the construction of the image is the result of a process of critical interpretation of reality, thus becoming a useful support for the preservation of the memory of the current state of the monuments. The most appropriate survey methodology will be determined from the formal characteristics of the object, but above all from the objective of the survey. It will be important to define the level of detail required prior to data capture. This will have a direct influence on the choice of technology, the necessary configurations, the size of the data and, therefore, the time and cost of the acquisition phase.

Today, as we have seen in the state-of-the-art chapter, technology applied to Cultural Heritage frequently uses instruments that do not require physical contact with the object for the acquisition of information in 3D format. These techniques make it possible to quickly record data in digital format with a high degree of accuracy, which is essential for the study and analysis of architectural objects.

Due to recent developments in computer vision and sensor technology, light has been used in various ways to measure objects. These measurement techniques can be divided into two categories: passive and active techniques. The former techniques, also called Image-based, do not emit any radiation, but instead rely on detecting reflected ambient radiation. Such techniques, also called photogrammetric techniques are based on multiple acquisitions of the scene taken by different viewpoints. The latter techniques, also called Range-based, emit some type of controlled radiation, and detect its reflection in order to probe an object or environment. Such instruments send an active signal to directly measure the distance to an object, e.g., lidar, sonar or radar.

Depending on the requirements and on the object properties and conditions, the appropriate technology has to be chosen, as each instrument is optimized for a certain purpose. When focusing on optical methods, data quality and project complexity depend on multiple parameters, e.g., Resolution, Distance to object, angle of incidence, Focal point, field of view, range, measurement time, accuracies.

Data processing occurs when data is collected and translated into usable information. Through the preparation, registration and alignment of data collected using different software environments.

To represent an object and its complexity it is necessary to adopt a general criterion, a synthesis code to graph the information. The objective is to highlight the original idea and the construction process; only in this way it will be possible to understand the object of study in all its aspects, and to acquire all the information for eventual intervention projects. According to CIPA, heritage recording, documentation and information management should be at the center of the ‘conservation management process’.

5.1.3. Modeling

The third phase concerns the geometric, technical, and semantic reconstruction of the object of study. In doing so, all the information of the object will be stored in a synchronized and collaborative platform. This has enormous advantages for the management of Cultural Heritage information.

The modeling phase represents an important step in a series of subsequent operations towards effective communication and enjoyment of heritage. The data from the first phase, collection, and the second phase, acquisition, provide an ideal framework for building a 3D digital dataset containing information on the entire life cycle of the heritage object. An effective strategy for preserving historical data is the so-called Building Information Modeling (BIM), through the creation of a “model of a building containing any information about its entire life cycle”. Within the framework of this methodology, applied to Cultural Heritage, we will refer to Historic BIM (HBIM), a strategy designed to support knowledge, management, and intervention actions on architectural heritage.

In this phase, a 3D database of all the information related to the historical object is defined. The information can be linked to spaces or components of the object of study which, together, constitute the complete three-dimensional model of the object, stored in a single, shared and easily updatable file. This 3D database can be intelligently interrogated and used for case study research.

Historic BIM can be used as a heritage management tool to aid future research and studies. Possible applications of BIM in the heritage sector vary according to the scope and purpose of the specific project and include: the creation of an information repository for documentation and recording activities, current condition monitoring, conservation planning, preventive maintenance, heritage interpretation, evaluation of intervention options, project management, basis for tourism promotion, academic visualization, immersive experiences, among others. Compared to BIM, HBIM puts more emphasis on the information behind the heritage building and is based on modeling techniques based on the data collected or acquired.

This phase, of technical reconstruction, will make it possible to understand the evolution of the object over time and therefore to understand its history in an innovative way, exploring the heritage, virtually and from a distance. These are comprehension activities that serve to document the level of knowledge of an object of study and provide information on the guidance and standards available to effectively manage the entire life cycle of a Cultural Heritage.

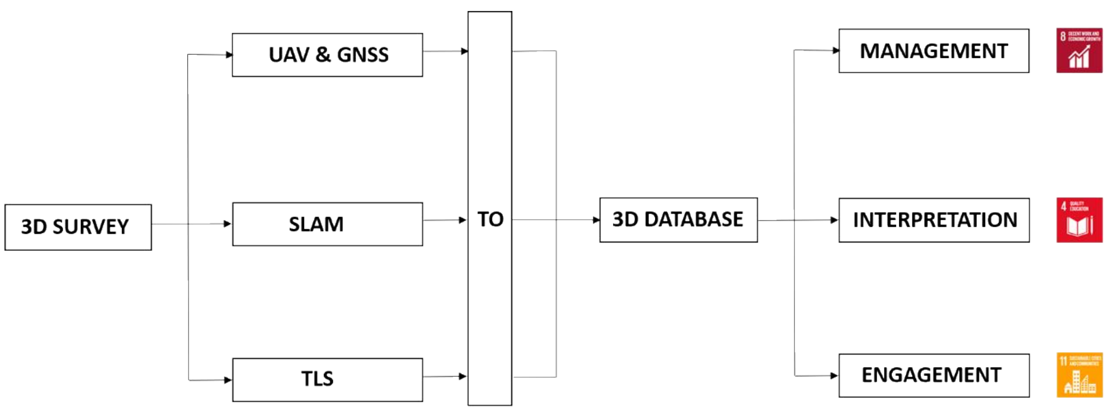


Fig. 23. Outline of the latter steps of the CAME Methodology.

5.1.4. Enhancement

The fourth phase is oriented to the dissemination of all the collected and processed data and information. The result of this phase becomes a tool for the promotion of the future activities, uses and expanded fruition of Cultural Heritage.

The historical research *(Collection)*, the survey of architecture *(Acquisition)* and the reconstruction *(Modeling)* are, in fact, indispensable tools of knowledge for the digital conservation of the Cultural Heritage. They allow to deepen information about an object in relation to fundamental aspects such as the historical becoming, the constructive process the type of material used, the construction system implemented, the proportions, the dimensions and other useful information for a scientific interpretation. From the level of deepening, but above all from the rigor and reliability of the data collected, it will depend on the correct historical interpretation of the architecture.

Due to 3D modeling techniques and extended reality, we will be able to discover our Cultural Heritage as if we were traveling in time, improving communication and interpretation skills through the development of enhanced architectural histories. In this phase, it is proposed: to generate content for interpreting and disseminating the architectural storytelling for remote public visits. This would help the public visualize and understand the history of a specific building, in addition to being a reusable and very useful didactical tool; To combine HBIM models with immersive extended reality as VR/AR visualization techniques to improve understanding about the hidden historical building traces and the building evolution as a whole.

The key points are analysis and documentation, but also sharing and communicating content and values in such a perspective, digital resources are crucial for dealing with tangible and intangible cultural assets. The information gathered using the methods listed above can be conveyed through the design of interactive applications and systems for multimedia devices and web platforms. This process involves the design and testing of augmented reality and 3D models for multimedia devices and the application of immersive reality.

The term augmented reality (AR) means the enrichment of our sensory perception through various levels of information, usually processed, and transmitted electronically, which would not be perceptible with the five senses. The information that augments the perceived reality can be added on the screen of a computer or mobile devices. Virtual reality (VR), on the other hand, arises from the desire to 'replicate' reality in a non-real world, reproducing its characteristics from the sensory point of view, to perform actions in virtual space, overcoming physical, economic and security limits. In virtual reality, information is added or subtracted electronically; data are reconstructed by a computer and become preponderant, to the point of deceiving the senses, with the sensation of being 'immersed' in a new situation, in a new reconstructed reality, which is precisely virtual.

These techniques propose new ways to improve and increase awareness of architecture, promoting communication methods to stimulate the public, such as storytelling to tell the story of a project. Strategies of emotional, awareness and dissemination help on reaching out to the community.

The methodology will provide a database of 3D Cultural Heritage for academic purposes that will eventually serve for successive requalification projects: to share best practices and methodologies for capturing, processing, and storing data on Cultural Heritage; moreover, to serve as a record of these sites in case of terrible loss or forgetfulness (Fig. 23). The result could also be a resource for those responsible for the management of these cultural sites, as well as for those interested in approaching Cultural Heritage.

L'architecture se compose de théorie et de pratique. La première est constituée, d'une part, de règles imputables aux traditions et aux éléments de caractère historique et empirique et, d'autre part, de formules scientifiques, démontrables, absolues, indubitables. Le seconde se définit, quant à elle, comme «l'application de la théorie aux besoins», c'est-à-dire la capacité d'adapter l'art et la science à des facteurs de nécessité, quels que soient l'endroit, les matériaux, le climat ou les coutumes d'une époque.

Eugène Viollet-le-Duc.

6. APPLICATIONS

6.1. A case study of a Historic Architecture in Italy

6.1.1. Introduction to Villa Rufolo in Ravello (40°38'57.5"N 14°36'42.6"E WGS84)

Villa Rufolo is located in Ravello, a small town in southern Italy, on the Amalfi Coast, included in the World Heritage List, UNESCO 1997[1] (Fig. 24). From the need of a complete documentation for its knowledge and expanded fruition, so far absent, it is motivated the application of the CAME methodology, in order to implement effective management and maintenance processes, potentially applicable to all Cultural Heritages.

This study begins as part of an academic experience, in the framework of a collaborative project between researchers of the Department of Civil Engineering of the University of Salerno and Villa Rufolo. This collaboration gave rise to the project *"A proposal for the expanded fruition of Historical Architecture of World Heritage Sites"* which is the frame of the Thesis. Within the scope of the project, several data collection and processing campaigns have been carried out, in the form of *laboratorio a cielo aperto* that aimed at experimenting new integrated survey techniques as a basis for a critical interpretation, with scientific rigor and precise knowledge; to respond to the increasingly emerging cases of recovery and conservation.

Fig. 24. Villa Rufolo on the Amalfi Coast. UAV Photo by Rocco D'Auria.

[1] https://whc.unesco.org/en/list/830/ (last accessed March 2021).

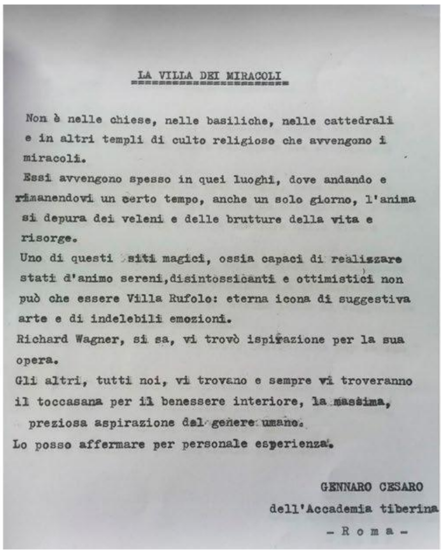
Fig. 25. Chiostro Moresco di Villa Rufolo. Photo by Pino Izzo.

Fig. 26. Chiostro Moresco di Villa Rufolo. Photo by Pino Izzo.

Villa Rufolo possesses a millenary history

Villa Rufolo is a ‘jewel in the crown’ of the town of Ravello, it holds within itself centuries of history and magnificent legends. It is a structure that has lived moments of glory and darkness, and is the owner of a style that, even today, continues to attract attention over the centuries, inspiring people of culture such as artists, writers, historians or simply lovers of beauty. Due to its strategic position on the shores of the Mediterranean Sea, the Amalfi Coast, during the Middle Ages, became a scenario of enormous cultural, natural, and commercial value, strengthening ties with the Middle East that promoted an exchange which was not limited only to trade, but extended to its own culture and artistic and architectural ideals. These ideals can still be observed today, with emblematic examples such as Villa Rufolo (Fig. 27). Despite the effects of time, the Villa has preserved many of the environments that make it one of the most interesting examples of twelfth-century architecture in southern Italy.

Historical architecture cannot be understood in its singularity[1]. It is not a simple geometry or a single element but the result of a complex series of transformations over time. In fact, the Villa or Palace of Oriental features, is a monument that has undergone numerous alterations over the centuries. Its construction can be traced back to the XII century[2], and during the following centuries, the Villa has changed its original appearance going through different phases, suffering periods of abandonment, degradation, divisions, incorporations, and restorations, promoted by the different owners that have succeeded one another. It is a monument that is immersed in an environment in continuous transformation that must coexist with ancient medieval testimonies.



LA VILLA DEI MIRACOLI

Non è nelle chiese, nelle basiliche, nelle cattedrali e in altri templi di culto religioso che avvengono i miracoli.
Essi avvengono spesso in quei luoghi, dove andando e rimanendovi un certo tempo, anche un solo giorno, l'anima si depura dei veleni e delle brutture della vita e risorge.
Uno di questi siti magici, ossia capaci di realizzare stati d'animo sereni,disintossicanti e ottimistici non può che essere Villa Rufolo: eterna icona di suggestiva arte e di indelebili emozioni.
Richard Wagner, si sa, vi trovò ispirazione per la sua opera.
Gli altri, tutti noi, vi trovano e sempre vi troveranno il toccasana per il benessere interiore, la massima, preziosa aspirazione del genere umano.
Lo posso affermare per personale esperienza.

GENNARO CESARO
dell'Accademia tiberina
- R o m a -

Fig. 27. Villa Rufolo in 1900. Photo by Luigi Cicalese.

[1] “Every old building is unique, with its own identity and its own distinctive character. Character refers to all those visual aspects and physical features that comprise the appearance of every historic building. Character-defining elements include the overall shape of the building, its materials, craftsmanship, decorative details, interior spaces and features, as well as the various aspects of its site and environment”. Stylianidis (2020).

[2] According to Camera, M. (1836), the Palace should date back to the XII century as it results from the architectural, artistic and stratigraphic interpretation of the monument.

Fig. 28. Panoramic view from Ravello.

Fig. 29. Panoramic view of Ravello.

Villa Rufolo is recognized as a famous source of inspiration, for Richard Wagner[1] for his romantic ideals and his *magical garden of Klingsor*, or Maurits Cornelis Escher[2] who found in the geometry of the belvedere gardens of Villa Rufolo, the illumination for some of his works (Fig. 30). However, despite its fame, and a good deal of general literature, the architectural history of the Villa, due to its complexity and numerous transformations, still has aspects that deserve an in-depth study. In order to carry out an exhaustive study of the Villa, it was necessary to collect as much information as possible to serve as a basis for its analysis, interpretation, and knowledge. In addition, one of the most important tools that allows us to approach such a study, is the construction of a relevant graphic documentation of the current state to compare it with archival documents or bibliographic sources.

The Rufolo Family has represented for several centuries the symbol of the economic and political power of medieval Ravello[3]. They were the economic source of the kingdom and their power was manifested in the construction of the residential house: the building, of Norman Campanian architecture, had to demonstrate their social status and it was through the Byzantine canons that they found the right language to achieve it[4]. The residential palace has almost unique architectural features, blending Arab-Byzantine typologies and ornaments with elements of the local culture. The power of the Rufolo Family declined in the XIII century, in 1282 they were accused of high treason to the Crown, having switched from the Aragon's throne to the Angevin during the wars of the Sicilian Vespers. The ambitious family was a real threat to the Crown, and after the condemnation, which involved death and exile, the Rufolo family never managed to overcome.

Fig. 30. Ravello and the Coast of Amalfi. Postcard Cicalese (1900), Painting Escher (1931), Sissi movie (1955).

[1] Wagner, the famous German composer, was so impressed by the beauty of the Villa Rufolo gardens during his visit in 1880 that he used them as the inspiration for his opera Parsifal. *"The enchanted garden of Klingsor has been found".* In his memory Ravello has become known, until today, as *'the city of music'*.

[2] When Escher, the famous Dutch artist, visited Ravello, remained attracted by the extraordinary relationship between *"the forms of landscape and those of architecture"*, which became the inspiration for his work.

[3] Ravello between the XII and XIII centuries had an urban development that consisted in an enlargement of the city, in the construction of several civil and ecclesiastical buildings, in the general restructuring of the fortifications and of the defensive system.

[4] *Sotto i sovrani angioini Carlo I, e II, quivi edificarono un sontuoso palagio a cui dava ingresso un porticato contornato di colonne ed intrecciato da fregi in forma semi-gotica, di un gusto tutto singolare. Questo palagio a suoi tempi il più meraviglioso fra quanti altri furono colà; venne abitato in varie occorrenze da' sovrani Carlo II e Roberto d'Angiò e più di un secolo prima dal papa Adriano IV che per svista il Freccia dice essere stato Urbano IV* (Camera M., 1836).

Origins and transformations until today

In the period of its maximum splendor, the Middle Ages, Villa Rufolo[1], according to the writings of important writers such as Bolvito[2] and Boccaccio[3], was magnificent and extended to sea level. However, there are no direct sources for some of the transcriptions referring to the palace, such as "its rooms reached the edge of the sea" or "it has more rooms than days of the year". Considering, opportunely, that in many cases it was only literature and fantasy, and not necessarily had to correspond to reality, the question is involuntary: *what has happened to Villa Rufolo and those rooms, have they been demolished, covered, underground... or have they simply never existed?*

Nowadays it is only possible to appreciate some parts of the original construction, such as the iconic *Chiostro Moresco*, the *Sala dei Cavalieri*[4], the *Torre d'ingresso* (Fig. 31), or the 30-meter-high *Torre Maggiore*[5], which represented the prestige of the family. From its origins to the present day, we can see how the building has witnessed a series of cultural and architectural changes that have left their mark over time. As previously expressed, the construction dates back to the mid-twelfth century and during the following centuries, the Villa has changed its original appearance through different phases, undergoing periods of abandonment, degradation, fractionations, and interventions promoted by the different owners that have succeeded one another, among which we can mention the Confalone, Muscettola and D'Afflitto families. Among the 'transformations' undergone, it is significant the one carried out by Sir Francis Neville Reid, a Scottish gentleman who bought the Villa in 1851, through restoration operations in romantic style and the creation of exotic English gardens, the Villa reached the period of its greatest splendor, positioning itself as a center of international cultural fervor.

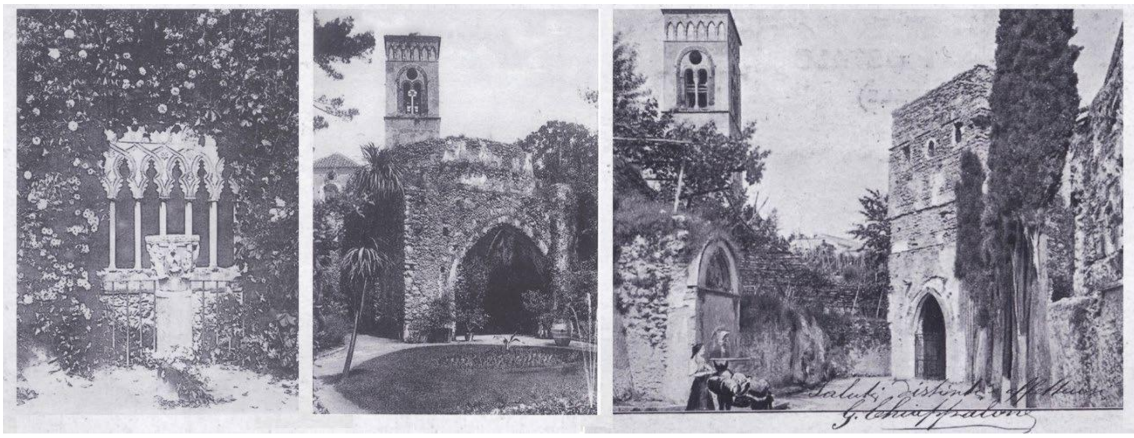


Fig. 31. Chiostro Moresco, Sala dei Cavalieri e Torre d'ingresso di Villa Rufolo by Luigi Cicalese.

[1] According to Gargano, G. (1997) "this building improperly called Villa, was actually a *magnum hospitium domorum*. The main residence of the Rufolo family, existing at least since the Swabian age".

[2] Giovanni Bolvito (~1567) wrote about the Rufolo Family and the evident demonstration of their infinite possessions. *"De la familia de Rufoli. Et suo magnificentissimo Palazzo a Ravello"* (Camera M., 1836).

[3] According to sources, Giovanni Boccaccio, after staying at Villa Rufolo between 1327 and 1340, wrote his Fourth Account of the Second Day of his work Decameron inspired by 'Landolfo' Rufolo, the ambitious merchant, his sudden fortune, and his precipitous fall. Furthermore, it seems that Boccaccio, when describing to *"the palace with a beautiful and large courtyard in the middle and with loggias and halls and wonderful gardens",* was referring precisely to Villa Rufolo.

[4] The *hospitium domorum* of the Rufolo's shows environments of Arabic style in the garden, with square base and originally covered with a wide dome (Gargano G., 1997).

[5] The imposing appearance of the towers during that period in the Amalfi Coast was not for defensive purposes but to impose fear and respect in the context and society.

Analysis of literature and many uncertainties

The collaboration with the direction of Villa Rufolo, started a critical journey that involved several disciplines. The first objective was to deep on the knowledge of a specific sector of the Villa, brought to light - after the excavations carried out at the end of the 90' - the thermal environments of Villa Rufolo, known as *Balnea*. The investigations carried out, allowed to query some hypotheses consolidated by the reference literature. For example, it was not explained why in a complex that was thought to be a single unit, there were two thermal environments with apparently similar functional characteristics, but formally very different from each other. On the one hand, the majestic Arab bath in the rooms of the belvedere garden, with the sumptuous dome of the *calidarium*, a space worthy of a noble palace, and on the other hand the thermal rooms of the *Balnea*, with its *calidarium* covered with a simple vaulted roof. Therefore, the first step was to prepare a new study through a scientific re-reading of the documentary sources and the implementation of novel acquisitions with remote sensing techniques.

New digitization allowed to support the theory that both spaces did not belong to the same complex since its origins. Theory verified later, with the information found in medieval archives, unpublished historical documents dated in the XII century, written in medieval Latin, which have allowed to suppose that those thermal environments that today we know as *Balnea* belonging to Villa Rufolo, were not so from their origins, but that, possibly, they belonged to an authentic *Medieval Domus of the XI century* (Amalfitano, Barba et al., 2019).

In order to verify the hypothesis, a documentary research and a comparative analysis have been carried out. Several Arab baths have been found on the Amalfi Coast with similar characteristics, some also immersed in noble palaces. It was therefore necessary to verify the available data and compare the apparent Arab baths of Villa Rufolo with the Arab bath of another similar structure in terms of function, typology, and age[1]: the *Palazzo Trara in Scala*, a medieval palace equipped with all the comforts appropriate to the well-being and power attained by its owners.[2]

The Arab baths between Ravello and Scala are examples of cultural exchanges with the Islamic world. These architectural works are the result of a mixture of different techniques and languages, whose appropriated and reinterpreted elements are integrated and fused into an original stylistic unity. From their hybrid architectural forms, the baths represented one of the manifestations of the influence of the Amalfi trade on the art and architecture of the region. In addition to the purely hygienic activity, the typology fulfilled a social function by being considered to be a meeting place. Numerous practices, both religious and social, have turned around bathing since ancient times, associated with the purification of body and soul.

It was a very diffused typology on the Amalfi Coast during the medieval period and was a symbol of the magnificence of the residences of the Amalfi nobility, it was not only limited to noble and rich houses, but it also extended to simple residential houses. These spaces, originally called *hammams*, have taken the name of 'Arab baths' or 'Turkish baths'.

[1] According to Gargano G. (1997), the whole complex seemed to be similar to the *hospitium domorum* of *Palazzo Trara* in Scala, with the umbrella dome of the entrance tower, the arabic decorations, the presence of arab baths, perimeter walls and towers.

[2] "The vestiges of many and rich palaces, with ornaments and decorations in marble, columns and stones of various colors, with the comforts of stoves baths and others, demonstrate the nobility and richness of the founders" (De Lellis C., 1654).

6.1.2. CAME Methodology application

These interrogations prompted the idea of conducting an in-depth study, taking advantage of the possibilities offered by the innovative technologies of architectural surveying.

Digital surveying plays a fundamental role in the documentation and analysis of architecture. It provides an interesting scientific basis for study and research, as well as ensuring an effective dissemination approach even for a non-technical audience. In the case study, several activities have been carried out over the years, to generate graphic material that facilitates historical interpretations becoming a tool for the design of strategies for heritage conservation (Fig. 32).

Different strategies have been experimented to analyze the history of the case study. Thus, favoring an effective tool that facilitates its interpretation through different multidisciplinary approaches, without neglecting the scientific and historical accuracy of the research. Within the scope of the Thesis, with a multidisciplinary team, it has been taken the initiative to contribute to the correct reading of the architectural object by applying the new technologies for documentation of heritage, to generate digital models that seek to order the reading of the object and serve as a basis to be potentially used for restoration and dissemination purposes (Fig. 33).

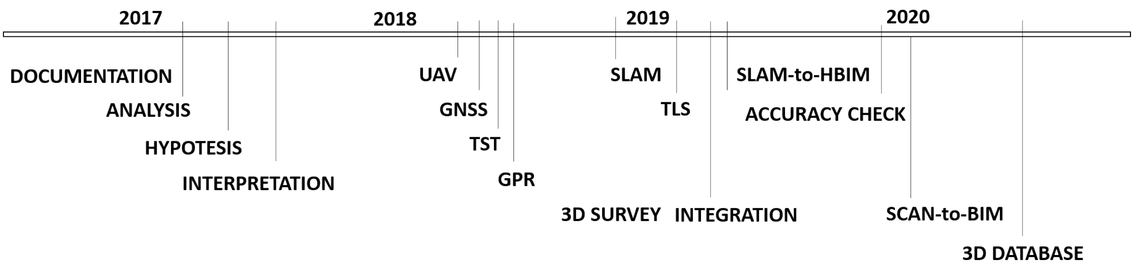


Fig. 32. Outline of the research conducted in Villa Rufolo over the last years.

Fig. 33. Digital model of Villa Rufolo.

The *Balnea* of Villa Rufolo in Ravello

The study of the *Balnea*, implies facing the challenge of the lack of documentation. For its digital documentation, an experience of survey with terrestrial laser scanning (TLS) technology has been implemented, which has allowed to generate a rigorous documentation in terms of accuracy and precision, necessary to advance in any new architectural analysis and to highlight information that is not immediately deductible.

The survey campaign was carried out with the use of a medium range laser scanner, the Faro Focus^{3D} x330 with integrated GPS receiver, which, under optimal environmental conditions, guarantees a scanning range of between 0.6 m and 330 m, a measurement speed of up to 976,000 points/s and a linearity error of between ±2 mm. The instrument was set up to acquire scans with an average resolution of 1/5 with a quality of 3x. Different stations have been placed to eliminate possible shadow cones, due both to the limits related to the fields of view (FOV) of the instrument and to the presence of objects interposed between it and the surfaces to be detected; and to the complexity of the geometry to be documented. A total of 33 TLS stations have been set up, and to facilitate data processing phases, six spherical targets were located at different heights and in strategic places to be viewed from multiple acquisitions. For data processing it has been used Faro Scene software (v. 5.1.6) that identifies homologous points between the different scans based on the recognition of the spheres.

To support the hypothesis that the *Balnea* was not an integral part of Villa Rufolo from its origin, the Arab bath located next to the belvedere garden, has also been recorded using the same procedure but limiting the number of scans. The geometry and characteristics of the *calidarium* of this new case study were undoubtedly similar to the case study that we will analyze below; while the *calidarium* of the *Balnea* consists of a small square room covered with a dome that, unlike the typical ribbed structures of Arab influence, presents a smaller size and a simplified cross-shaped configuration (Fig. 34).

Fig. 34. The Faro Focus^{3D} x330 in the Balnea of Villa Rufolo in Ravello.

The Arab bath of Palazzo Trara in Scala

The excellent state of preservation of the Arab bath in the *Palazzo Trara*[1] allows an exhaustive reconstruction of the stylistic-formal elements that defined the spatiality of these typologies scattered throughout the territory. It has been used once more the TLS technology, that accurately and repeatedly measures distance using laser pulse, by precise measurement of time needed for the laser pulse to travel from the object and back and transforms these measurements into a point cloud, from which information on the morphology of the object being scanned may be derived.

There are two primary means of measuring distance with a laser, one by calculating the time of flight (TOF) for a laser pulse to be sent, reflected from a surface, and returned, and the other by calculating the phase shift (PS) induced in a sinusoidally encoded beam after travel, reflect, and return. Each technique presents certain advantages and is chosen generally as a function of the type of scanning work to be accomplished. The technology is advancing with impressive rapidity, however, driven by a greater demand for speed, accuracy, and portability, and limitations are regularly overturned as scanner hardware evolves.

For the survey campaign, this time, an innovative - for 2018 - instrument has been used. A new time of flight laser scanner instrument of Leica with wave form digitizing technology that has the advantage of being able to acquire high resolution data in a very short time. The BLK360, with a wavelength of 830 nm, capturing up to 360,000 points/s, with a maximum nominal range of 60 m and an estimated resolution of 4 mm, was used for the survey (Fig. 35).

Fig. 35. The BLK360 in the Arab Bath of Palazzo Trara in Scala.

[1] These baths belonged to the Swabian epoch, they had two small communicating rooms, one covered with a radial umbrella dome painted in white and red, the other covered with a ribbed vault (Gargano G., 1997).

Regarding the performance of the instrument, the measurement speed takes less than 3 min for a full scan, with spherical and thermal imaging; and a 3D point accuracy of 6 mm. The instrument also has a system of 3 internal 15 MP cameras and a thermal camera. With High Dynamic Range (HDR) technology, which combines multiple over- and underexposed images to avoid loss of detail in high-contrast scenes. It is a user-friendly instrument, one-button scanning control and remote control via tablet Remote operation iPad app. It has real-time processing and transmission of images and scanned data. It has the capability to perform in-situ-pre-registration, cloud-to-cloud point processing and target-based post-processing (Table 1).

Maximum range	60 m
FOV	360° x 300°
Scan points per second	360,000 points/s
Scan range noise	± 5 mm
Laser safety classification	Class 1 Eye-safe per IEC 60825-1:2007 & 2014
Laser wavelength	830 nm
Operating temperature	5 °C to 40 °C
Weight	1 kg
Dimensions	Height: 165 mm/ Diameter: 100 mm
Battery life	Approx. 3.5 hours continuous use
Protection Class	IP54

Table 1. Leica BLK360 specifications.

For the case study of the Arab bath in *Palazzo Trara*, 12 TLS stations were set up and 6 spherical targets were distributed throughout the environment to facilitate the registration process. In total the survey lasted 3 hours. The acquired data were processed with 3 different data processing software, Autodesk Recap, Leica Cyclone and Faro Scene, comparing the results. The final 3D point cloud had more than 150 million points. The results obtained served as a basis for analyzing the geometry of the elements and comparing them with the cases of Villa Rufolo. In addition, they were useful tools to make hypotheses of restoration and valorization of the space for a dissemination project and a subsequent expanded fruition.

The Arab bath of *Palazzo Trara*, being located in a residential building[1], has a simplified structure, with reduced dimensions, and a heating system hypothetically represented simply by a wood oven placed under a basin containing the water to be heated. One of the most extraordinary solutions of the Arab baths was the radial dome that covers the *calidarium*, covered with waterproof malt, and supported by pointed arches; its shape resembled an umbrella, it was due to a purely practical solution, the ribs had the function of collecting the condensation drops of the thermal steam in a system of small channels located at its base. The articulated space determined a hierarchy between the vaulted compartment and the lateral areas according to a typically Byzantine conception that, as previously anticipated, have influenced the medieval architecture of the Amalfi Coast and had been reinterpreted with the ancient local construction techniques.

[1] This residence, today belonging to a private owner, is a real surprise: in a vast complex of ribbed vaulted wall structures and a small central courtyard, one can clearly identify the Arab bath, consisting of a small square room, about two meters long and half a side, covered with a small umbrella dome, set by spherical pendentives, over four pointed arches, open on opposite sides. The environment, with a clear Arabic imprint, was preserved intact until a few years ago. Time and neglect have rendered illegible the fresco decorations of the portal, which recalls, the dome of one of the towers of Palazzo Rufolo but which, at a closer look, is even identical to the bathroom of the same palace in Ravello (White A., 2016).

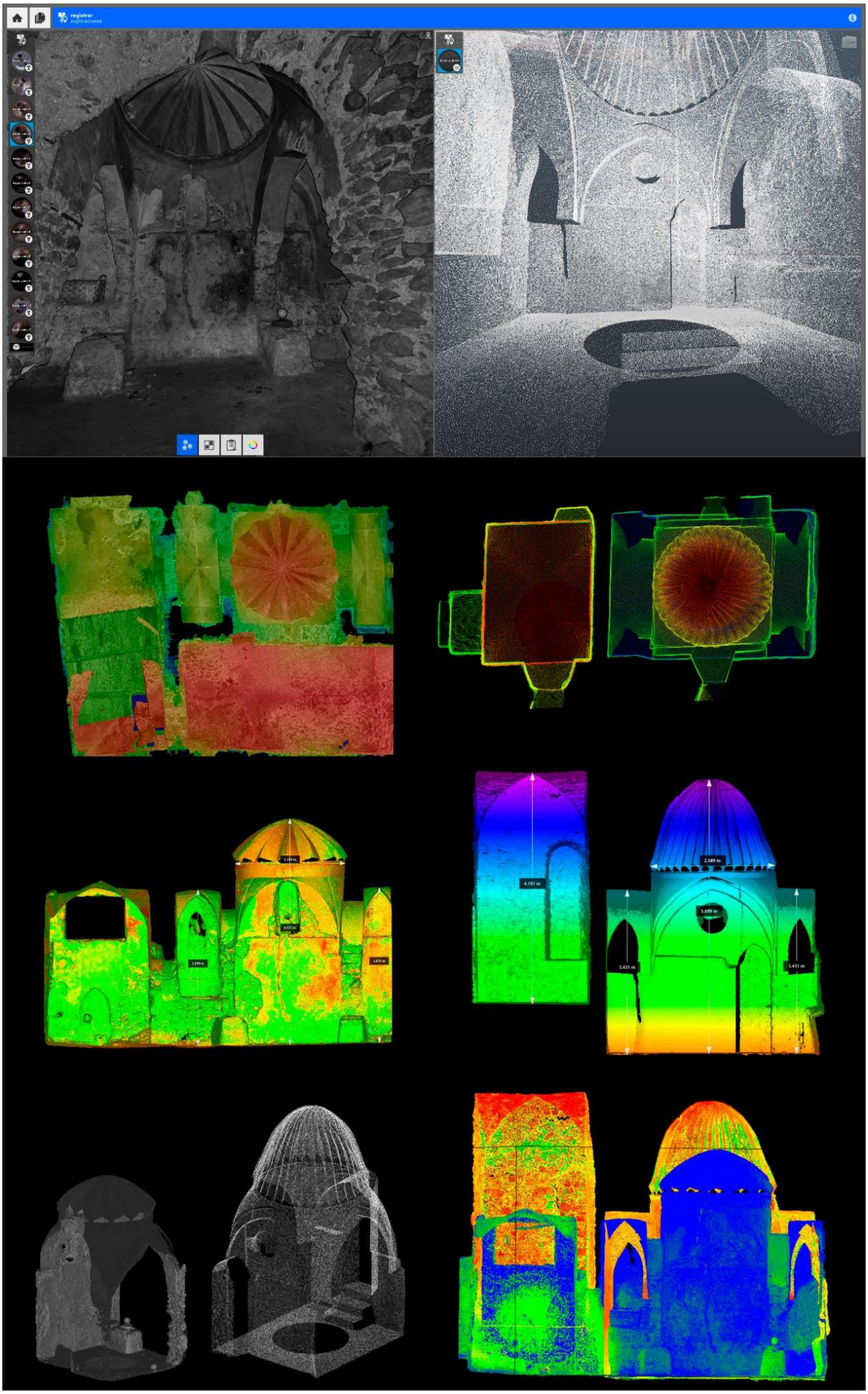


Fig. 36. Comparison between the Arab Baths in Palazzo Trara and Villa Rufolo.

Comparisons and analysis

The results obtained, 3D point clouds, views, sections, and high-resolution plans, document the spaces and promote the verification and analysis of the hypotheses raised (Fig. 36). The historical-critical analysis clearly shows the difference between the thermal environments of the Arab bath and the *Balnea* of Villa Rufolo. The latter, in fact, have a more 'austere' language: the environment of the relative *calidarium* is covered by a small-ribbed vault, and not with umbrella dome like those of the Arab baths of Villa Rufolo in Ravello or Palazzo Trara in Scala (Fig. 37).

Although the functional layout corresponds to the same typology, the size of the *Balnea calidarium* is considerably smaller. The reduced space of the *calidarium* indicates that it was designed to accommodate, for example, very few people, suggesting the image of a bath of a personal and/or individual type, rather than one intended for a social gathering or shared activity. Further reinforcing the hypothesis of the introduction: both spaces, the *Balnea* and the Arab bath of Villa Rufolo did not belong to the same complex since its origins.

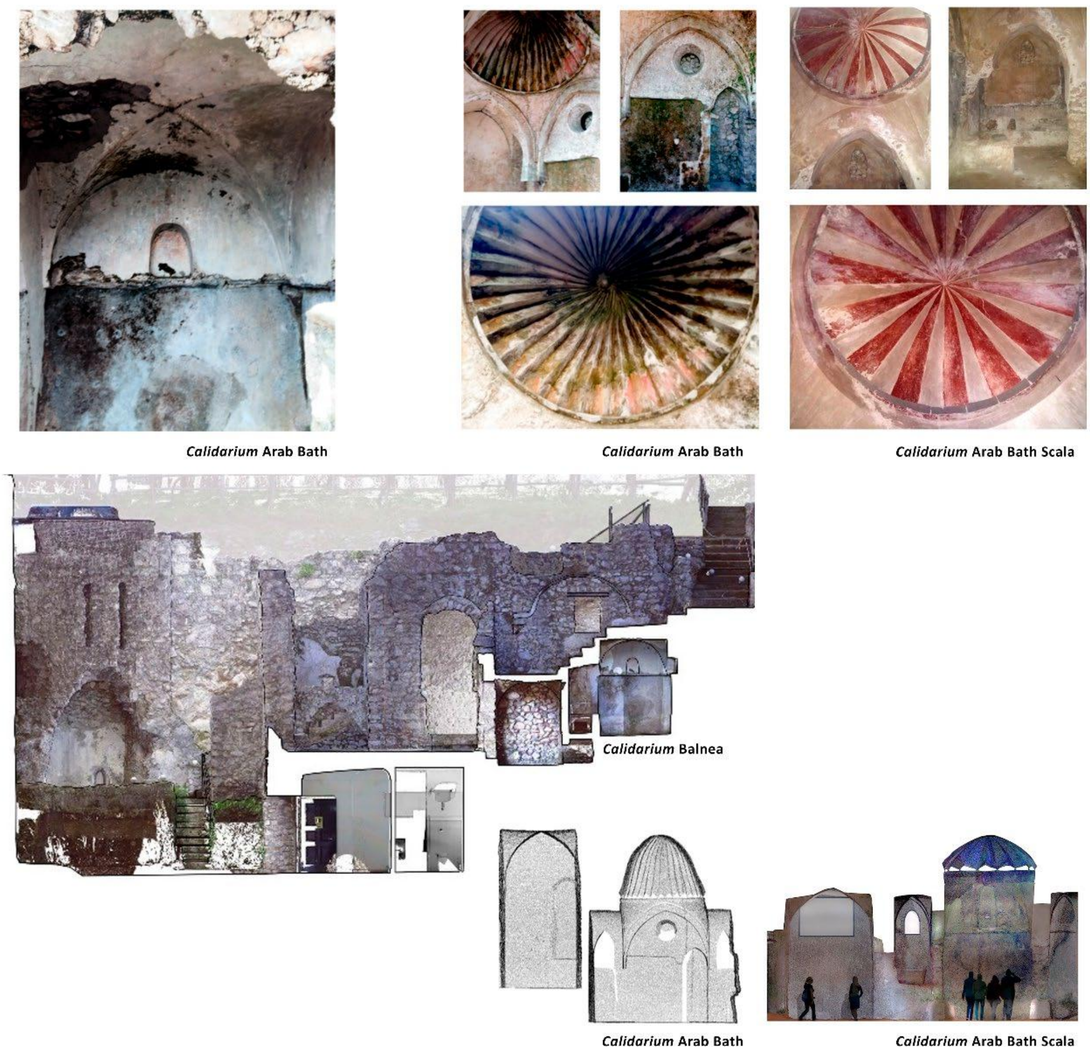


Fig. 37. Comparison between the 'Balnea' and the Arab Baths of Villa Rufolo and Palazzo Trara.

Fig. 38. Chiostro Moresco di Villa Rufolo.

Fig. 39. Chiostro Moresco di Villa Rufolo.

Need to extend the investigation to Villa Rufolo

The preceding knowledge tools were indispensable to start the research and enrich the existing documentation. Accurate documentation is essential to begin any study or analysis of an architectural-archaeological object such as the case study. From a documentary research and a timely in situ survey, it has been possible to question the traditional reference literature and to assume that what is currently known as Villa Rufolo is actually the sum of several adjacent properties acquired only in the nineteenth century. This revelation has laid the foundations for new research with the contribution of various sectors such as architectural history, graphic engineering, and architectural restoration.

Given the discoveries and the inconsistency in the bibliographic sources, it was necessary to extend the exhaustive analysis to the entire Villa Rufolo. Numerous studies and hypotheses have been formulated on the construction phases, but the lack, often, of accompanying graphic documentation - possibly restored with the help of the most innovative systems for the study of architecture - has led to the need to evaluate the reformulation of some of the most important phases of the chronology of Villa Rufolo.

It has been detected the need to deepen a study on Villa Rufolo, and for this reason, it is necessary to collect as much existing information as possible to serve as a basis for its reading and knowledge. In addition, one of the most important tools that allows us to approach this study is the construction of the pertinent updated graphic documentation. With the advantages provided by contemporary methodologies, we have carried out a survey experience using remote sensing technologies, which allows us to generate a documentation with accurate results, with error values to the millimeter. The building, with few plans and previous documentation, was inspected with an integrated approach using laser scanning and photogrammetry techniques. This integrated data served as the basis for a metrically reliable HBIM model, with information of different nature, which was used in a knowledge, maintenance, and restoration project. Tools for digital preservation continue to improve with advances in technology and research. As technology improves, these tools also become more accessible to communities.

The research has a cross section that focused on a new way of ‘writing’ history through the innovative use of information and communication technologies. These innovative visualization methods not only provide a scientifically valid basis, but also represent one of the most powerful means of dissemination as a testimony of our immaterial memory. The possibilities offered by the CAME methodology have allowed us to plan the continuation of the study, having all the necessary information for further activities of protection and fruition, starting point for the procedures of material defense of Cultural Heritage (Fig. 40).

Fig. 40. CAME - workflow implemented in Villa Rufolo.

Fig. 41. Sala dei Cavalieri in Villa Rufolo.

Fig. 42. Sala dei Cavalieri in Villa Rufolo.

UAV & GNSS BASED PHOTOGRAMMETRY

Photo (light) - *Gramma* (draw) - *Metry* (measurement)

Photogrammetry is the science of making measurements from photographs. It is an image-based, passive remote sensing technique, i.e., it uses the light present in the environment to acquire the images that will then be processed. As defined by ISPRS (2018), photogrammetry is "the art, science, and technology of obtaining reliable information from non-conduct imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation".

Photogrammetry, the most widely used passive sensor survey technique, estimates the 3D coordinates of a recognizable point in space using at least two photos of this point taken from different positions. The position of the photographed point in each photo implicitly defines a ray that goes from the point in 3D space to its projection on the camera sensor plane. The presence of at least two rays originating from two different camera positions makes it possible to find an intersection in space that identifies the 3D coordinates of the photographed point from the 2D coordinates of its projections in two photographs. This condition is called 'collinearity' and refers to the alignment on the same line of the 3D point in space, the center of projection of the camera and the point projected on the photograph. The collinearity condition is represented mathematically by a system of two equations, called the 'collinearity equations', which provide the projection coordinates on the sensor of a point, given its 3D coordinates, the position and orientation of the camera (extrinsic parameters) and a set of parameters representing how the camera affects the projection (intrinsic parameters). The intrinsic parameters include the focal length of the lens used to take the image and a set of parameters that consider the physical phenomena occurring in a real camera that tends to make photographic images different and real from a theoretical perspective projection. These parameters define the various distortions of the lens and the misalignment of the sensor with respect to the optical axis of the lens due to the mechanical tolerances of the camera (Kraus et al., 2007).

In general, these techniques, being required as knowledge tools to deduce valuable information, are characterized by high accuracy and reliability of the represented dimensions. Photogrammetry is suitable to use on highly complex objects, given the high geometric accuracy and the high level of detail that can be achieved. As accurate non-contact measuring method it provides powerful means for solving different tasks in object surface reconstruction and analysis, it allows to obtain information such as geometry, dimensions, position, and color of an object. Photogrammetry techniques, with the evolution of Structure from Motion (SFM) computational algorithms, are much faster and are largely automated (Stylianidis & Remondino, 2016).

The SFM technique uses a sequence of images acquired by a moving camera to estimate 3D objects. It allows to convert the 2D (x,y) coordinates information of the characteristic points of an object recorded in two or more images of a photographed scene into 3D coordinates (X,Y,Z). Through the generation of a high-density 3D point cloud of an object. In a SFM workflow, images from many angles and distances can be used; and no prior knowledge of locations or position is required. In general, SFM allows the acquisition of 'unstructured' imagery from the ground or from unmanned platforms, such as drones (Barba, Barbarella, et al., 2019).

Small Unmanned Aerial Vehicles (UAVs), commonly called drones, are gaining popularity not only among the general public, but also among professionals working in the AEC industry. The ability to equip drones with high-definition cameras, infrared scanners and/or thermal sensors makes it possible to collect important data that can affect a project from the design, construction or monitoring phase.

One aspect to consider is the ever-changing regulations on the use of drones[1], for example, drones must fly within line of sight, at altitudes less than 150 m and with a maximum take-off weight of less than 25 kg.

For Villa Rufolo case study, the UAV photogrammetry technique, known as aerial photogrammetry, was implemented.

This technique has a strong dependence on weather conditions, for example, wind is a complication for the stability of the instrument, as well as shadows on objects make data processing difficult. However, there are many advantages of aerial photogrammetry over other remote sensing techniques such as laser scanning. On the one hand, the undoubtedly lower cost of the instrument or the greater speed of data acquisition. However, the possibility of obtaining a photorealistic textured model is the greatest advantage of the technique. Since the images contain all the information necessary to reproduce both the geometry and the texture of the photographed object, photogrammetric methods make it possible to generate three-dimensional models with an optimal information content. In the field of architectural restoration, chromatic data are as important as the rigorous determination of the geometry, in order to recognize the stratigraphic units. Therefore, image-based techniques are well suited for the study of architectural surfaces and their subsequent interpretation.

Fig. 43. The GNSS Geomax Zenith 25 and the UAV Phantom 4 in Villa Rufolo.

[1] According to Ente nazionale per l'aviazione civile (ENAC) https://www.enac.gov.it/ (last accessed March 2021).

Survey planning

The need to acquire and manage accurate and georeferenced three-dimensional data of Villa Rufolo and its surroundings motivated the aerial photogrammetric survey campaign conducted in 2018 with an UAV, a DJI Phantom 4. The UAV survey of the Villa was accurately georeferenced from external ground control points measured with a Geomax Zenith 25 GNSS receiver with nRTK (Fig. 43).

The Phantom 4 is an aircraft weighing approximately 1.4 kg, capable of capturing images and recording videos in 4K and transmitting them to smartphones, tablets, or other external devices by the DJI Go App. The camera is equipped with a 12 MP Sony Exmor sensor (6.3 x 4.7 mm, pixel 1.56 µm), has a wide-angle lens with a focal length of 4 mm and a FOV of 94°. The camera is integrated into the device to maximize image stability during movements. The quadcopter is characterized by a maximum flight autonomy of 28 minutes and has the ability to independently avoid obstacles (Table 2).

Sensor	1/2.3" CMOS – 12.4 M effective pixels
Lens	FOV 94° 20 mm /24 mm - f/2.8
ISO Range	100
Electronic Shutter Speed	1/765 s
Resolution	4K
Frames per Second	30
Operating Temperature	0 °C to 40 °C
Stabilization	Gimbal 3-axis (pitch, roll,yaw)
Weight	1.38 kg
Diagonal Size	350 mm
Max Flight Time	Approx. 30 minutes

Table 2. DJI Phantom 4 specifications.

For the georeferencing of the data generated by the photogrammetric acquisition, it was necessary to measure the GCPs, marked on the ground by the photogrammetric targets, by means of a GNSS. In the case study it was used the Geomax Zenith 25, a two-phase receiver capable of acquiring signals from satellites[1] and returning the coordinates of a point according to a global reference system with an accuracy of ± 1 cm in the horizontal plane and ± 2.5 cm in the vertical plane (Table 3).

Channels	120 dual frequency
Accuracy	5 mm ± 0.5 ppm (rms) static vertical
Module	406 MHz to 480 MHz
Bluetooth	Device class II
TNC connector	UHF antenna
Operating Temperature	-30 °C to 60 °C
Weight	1.20 kg including battery and internal UHF radio
Dimensions	Height 95 mm ø 198 mm
Operating time	6 h in rover mode
Protection Class	IP68

Table 3. Geomax Zenith 25 specifications.

[1] The position of the GNSS receiver is calculated by measuring the time taken for a radio signal to travel to it from the satellites. By observing this interval for at least four satellites, the system is able to calculate the position of the receiver. Since the radio signal must pass through the atmosphere, it is affected by various factors that introduce errors into the measurements. It is therefore essential to use equipment capable of quantifying and eliminating these sources of error. https://geomax-positioning.com/

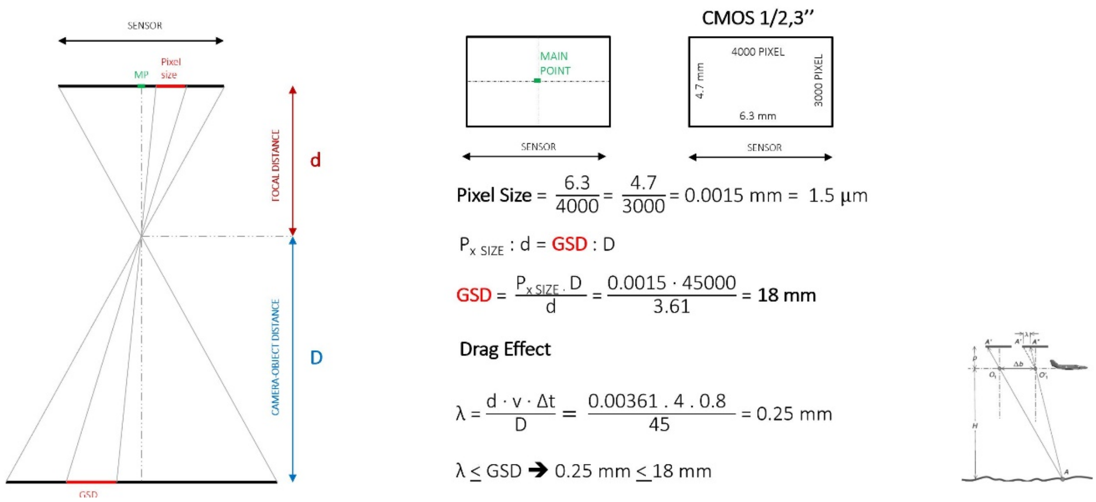


Fig. 44. Calculation of Ground Sample Distance.

For the georeferencing of the project, 14 targets were uniformly distributed in the area to be surveyed. Artificial topographic targets (black and white 42 x 29.7 cm) were used. The size of the targets needs to be at least 5 times larger than the design GSD (Ground Sample Distance), so that they can be clearly and accurately identified in the image during photogrammetric processes. In the case of the study, the 14 GCP (Ground Control Point) were beaten with the Zenith in nRTK (Network Real Time Kinematic) mode by placing the instrumentation in the center of the target, for a few minutes, to obtain the most accurate measurement possible.

In order to obtain highly accurate results, it was necessary to carefully design the flight plan, using specific instrument applications such as DJI Ground-Station. It is necessary to ensure that all geometry is captured by images with sufficient overlapping information, avoiding large distances between photos. This survey mode allows us to reconstruct the three-dimensionality of the observed scene using several frames. To ensure good survey quality, it is essential to have adequate weather conditions and homogeneous illumination; and to avoid, as far as possible, shiny, reflective, or transparent objects, as well as moving objects.

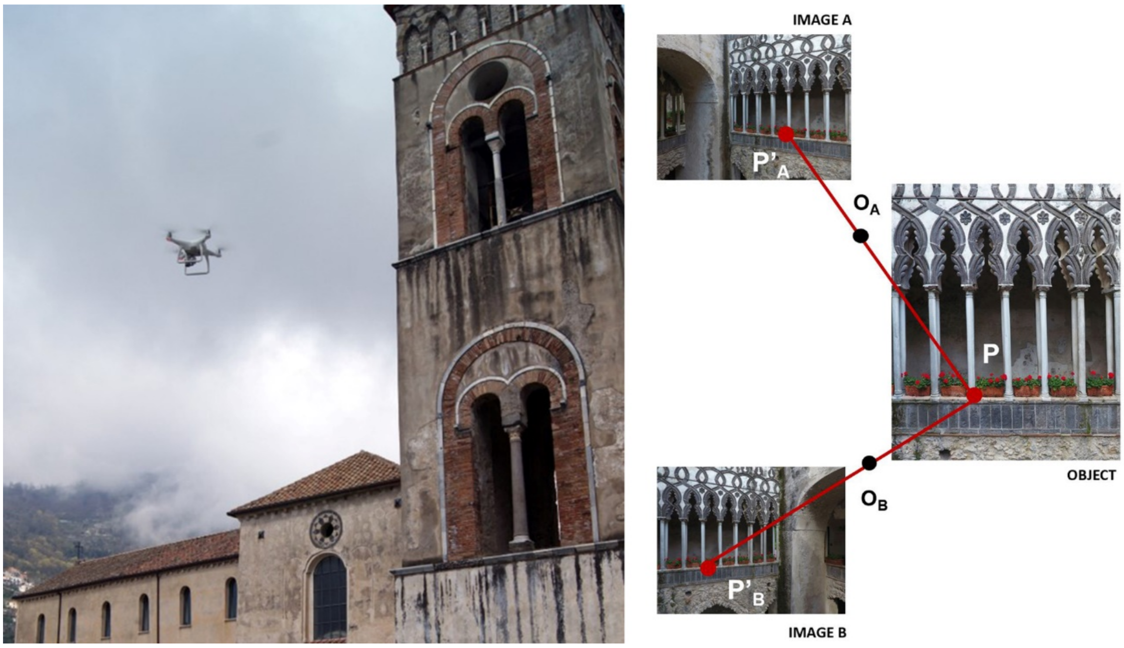


Fig. 45. UAV & GNSS - Data Capture.

Data capture

The drone was piloted by radio control and monitored in real time using a tablet. Flight plans, using the DJI Ground-Station software package, were set up so that the drone crossed the area in two directions as orthogonal as possible to obtain a grid covering a total area of about 117,000 m^2.

Four flight plans were established in automatic mode maintaining a horizontal velocity of 4 m/s. Based on the technical specifications of the camera sensor (6.3 x 4.7 mm, pixel 1.56 µm), the height of the flight plane was determined, calculating a GSD of 18 mm (Fig. 44). The flight altitude was also determined according to the obstacles present in the area, therefore, to ensure the device safety, the UAV flight at a constant height of 16 m above the take-off point, the highest element in the area, the *Torre Maggiore*. The height was defined in the application using elevation data derived from Google Earth.

The first two flight plans had two perpendicular grids, acquired in nadir mode, i.e., perpendicular to the earth's surface. Subsequently, the next two flight plans, still in automatic mode, again had two perpendicular grids in oblique mode, i.e., with the camera tilted at 45°. The choice of acquiring oblique images was necessary to better acquire texture information on some vertical elements, and simultaneously increase the accuracy of the photogrammetric survey. In the case of using only the nadir mode, many details regarding the height of the elements would be lost, therefore, the combination of the acquisition modes was advantageous to improve the definition of the geometry, the continuity of the surfaces and the height of the elements.

For each of the flight plans, the parallel flight lines are programmed to have a 60% image overlap and sidelap, setting the appropriate camera parameters such as sensor dimensions, focal length, and flight height. In nadir mode flights, 93 images are acquired in the first grid, from North to South, and 94 images in the second grid, from West to East. The following flight plans, with the camera tilted at 45° with respect to the horizontal plane, acquire, respectively, another 92 and 163 images. The image acquisition is planned to consider the project requirements, i.e., ensuring a ground sample distance (GSD) of about 1 cm and, at the same time, guaranteeing a high level of automation at each stage.

In addition to the surveys of the entire area of Villa Rufolo, a detailed survey of its *Chiostro Moresco* was also carried out. The *Chiostro* has a covered area of approximately 150 m^2 and an uncovered area of 60 m^2. In this case, the aerial photogrammetric survey methodology was implemented again, but this time, we proceeded in a different way, performing for the first time a manual acquisition, moving the device along the entire vertical axis of this element in a 16 x 9 m area. The photogrammetric images were captured in manual mode with a non-constant overlap estimated at an average of 80%. In total, for the *Chiostro*, using the same UAV as for the survey of the entire Villa, 378 images were acquired, which made it possible to generate orthoimages of the 4 interior walls with a GSD of 5 mm. The subsequent integration with other techniques made it possible to overcome the obstacle of working with divergent captures - in bibliography convergent captures were required - and to ensure even with this modality, innovative for 2018, the capture of a high level of detail (Fig. 45).

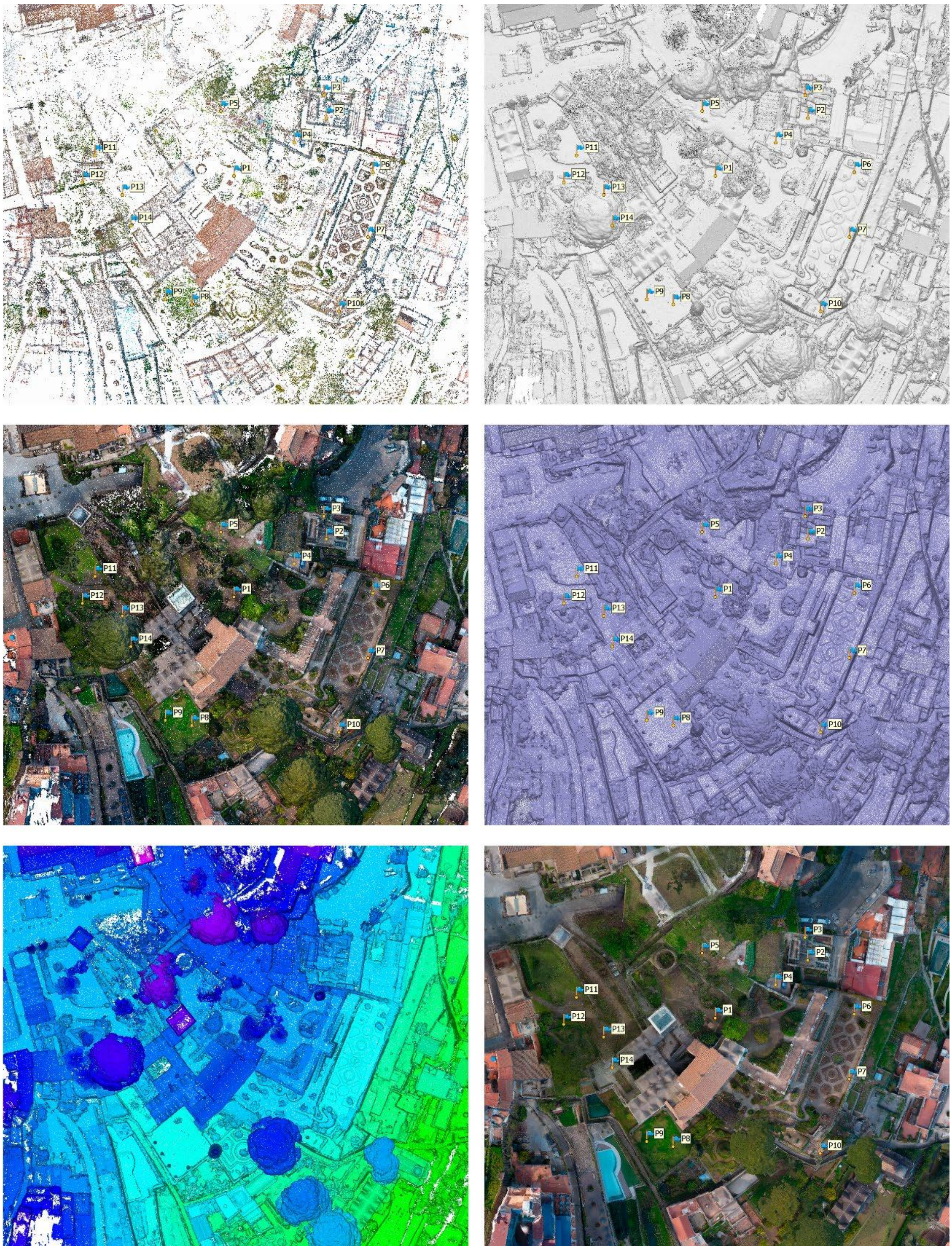


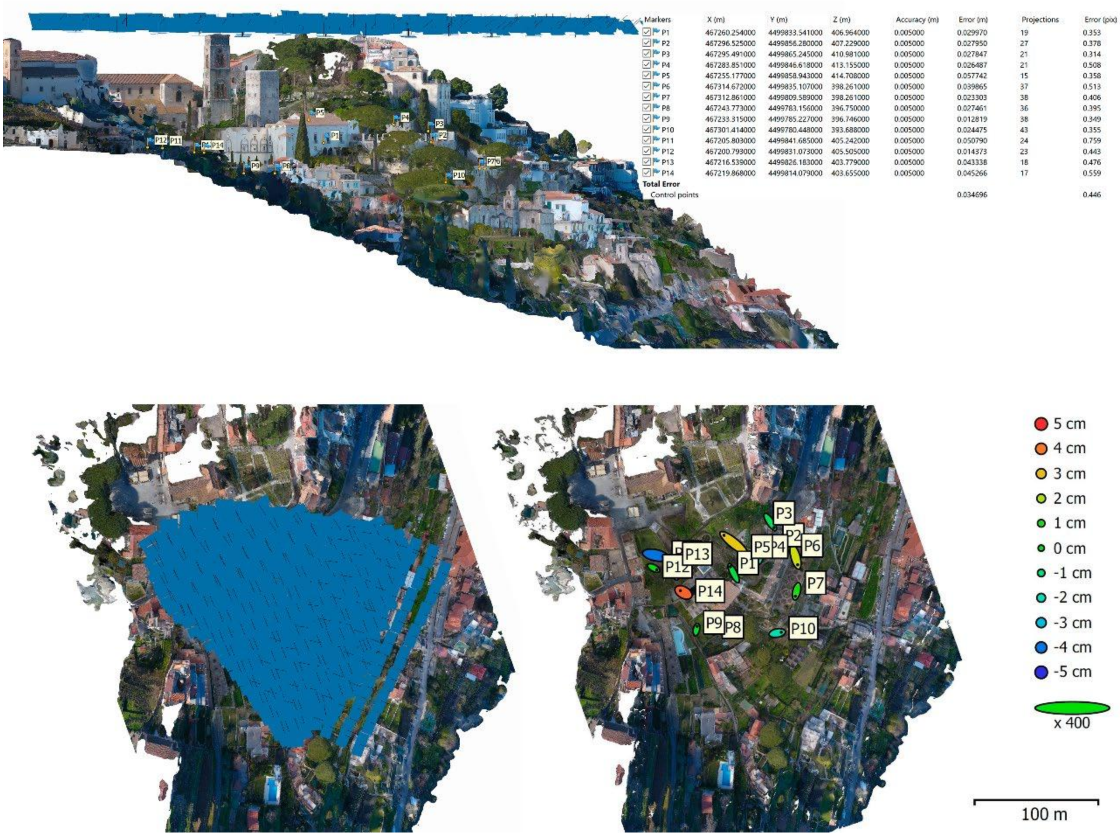
Fig. 46. Point clouds, polygonal model, digital elevation model and orthoimages of Villa Rufolo.

Data processing

The processing of the photogrammetric data was performed with Agisoft Metashape software (v. 1.4.1 build 5925). The first step was to properly select the images to be used, in total, for the entire Villa and its surroundings, 442 photos have been used. The adopted workflow is based on four steps: Align Photos, Build Dense Cloud, Build Mesh and Build Texture. In the first step an algorithm evaluates the internal parameters of the camera (focal length, main point position, radial and tangential distortions), and determines the camera positions for each image, creating a sparse cloud. In the next phase, a larger number of pixels are again projected for each aligned camera, creating the Dense Cloud. In the Build Mesh step, it is possible to generate a polygonal mesh model based on the dense cloud data. Finally, this polygonal model is textured through the Build Texture step.

The internal orientation parameters were estimated in Metashape using a bundle adjustment by including the coordinates of the GCPs, to improve the metric results (Fig. 47). These estimated parameters were used to orient the images and were kept constant throughout the SFM processing. From the complete processing of the images of the entire Villa Rufolo, a colored and georeferenced point cloud of 48,728,732 points was obtained, with an average error in the GCPs of about 2.8 cm. The dense point cloud was used as the basis for the construction of a textured mesh of 3,248,565 faces and 1,635,777 vertices and the construction of the texture of size 4,096 x 4,096 px (Fig. 46).

For the *Chiostro Moresco*, the point cloud produced, georeferenced in the same reference system as the cloud of the entire Villa, has 1,341,031 points, from which a mesh with 894,015 faces and texture of 4,096 x 4,096 px was subsequently extrapolated (Figs. 48, 49).



Markers	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
P1	467260.254000	4499833.541000	406.964000	0.005000	0.029970	19	0.353
P2	467296.525000	4499856.280000	407.229000	0.005000	0.027950	27	0.378
P3	467295.491000	4499865.245000	410.981000	0.005000	0.027847	21	0.314
P4	467283.851000	4499846.618000	413.155000	0.005000	0.026487	21	0.508
P5	467255.177000	4499858.943000	414.708000	0.005000	0.057742	15	0.358
P6	467314.672000	4499835.107000	398.261000	0.005000	0.039865	37	0.513
P7	467312.861000	4499809.589000	398.261000	0.005000	0.023303	38	0.406
P8	467243.773000	4499783.156000	396.750000	0.005000	0.027461	36	0.395
P9	467233.315000	4499785.227000	396.746000	0.005000	0.012819	38	0.349
P10	467301.414000	4499780.448000	393.688000	0.005000	0.024475	43	0.355
P11	467205.803000	4499841.685000	405.242000	0.005000	0.050790	24	0.759
P12	467200.793000	4499831.073000	405.505000	0.005000	0.014373	23	0.443
P13	467216.539000	4499826.183000	403.779000	0.005000	0.043338	18	0.476
P14	467219.868000	4499814.079000	403.655000	0.005000	0.045266	17	0.559
Total Error							
Control points					0.034696		0.446

Fig. 47. Ground Control Points location and error estimates.

Fig. 48. Point clouds, polygonal model, and orthoimage of Chiostro Moresco of Villa Rufolo.

Fig. 49. Orthoimages of the Chiostro Moresco of Villa Rufolo.

Results

The photogrammetric survey has made possible to update the as-built documentation of the case study and to facilitate a digital reconstruction characterized by rigor and metric reliability.

Point clouds, polygonal surface models, digital elevation models and high-resolution georeferenced orthoimages with high technical and centimetric accuracy were obtained. This allowed the generation of technical pieces of an architectural scale of 1:50 which helped to document the current state of conservation of the case study and to analyze the possible chronological phases allowing us to understand the limits of Villa Rufolo (Figs. 51, 52).

The research and analysis of archival documentation has been fundamental to provide veracity to the research. The documents analyzed are valid evidence that provide the necessary scientific rigor to the hypotheses developed.

This georeferenced 3D model allows us to elaborate 2D documents with a high degree of detail that serve as a basis for eventual restoration or maintenance projects (Figs. 53, 54). In addition, the point cloud can also be considered an effective solution for keeping Cultural Heritage virtually accessible. Current digital survey techniques, therefore, play a fundamental role in the documentation of Cultural Heritage. In addition to have an effective dissemination approach for a non-technical audience, it is a tool that provides an interesting and innovative scientific basis for study, analysis, and research. The material produced facilitates historical interpretations and is a tool for designing strategies for Cultural Heritage protection, conservation, and expanded fruition (Fig. 50).

Fig. 50. UAV & GNSS point cloud of Villa Rufolo.

Fig. 51. Orthoimage of Villa Rufolo.

Fig. 52. Comparison between Villa Rufolo plan of 2008, in red, and plan of 2018, in black.

Fig. 53. North-East elevation of Villa Rufolo.

Fig. 54. South-East elevation of Villa Rufolo.

GPR-BASED ANALYSIS

To not limit ourselves only to the survey of the visible, geophysical investigations, were carried out, which allowed us to verify anomalies potentially associated with buried architectural-archaeological structures as well as to obtain the necessary information. Ground Penetrating Radar (GPR) has been one of the most widely used tools for archaeological survey in the last two decades (Conyers, 2010) due to the high-resolution data and its 3D visualization capability. GPR transmits a very short pulse of electromagnetic energy and measures a reflected signal that depends on the dielectric properties of the subsurface material. The delay of the reflected signal is used to estimate the depth range of the target. The latter and the resolution are related to the radar frequency, the dielectric properties of the host material, and the shape and dimensions of the objective. The HI-Mod GPR system with dual antenna with a central frequency acquisition band of 200 and 600 MHz (Table 4) was implemented in Villa Rufolo to analyze the electromagnetic response of the underground (Fig. 55).[1]

Radar Acquisition unit	IDS DAD FAST WAVE with RIS K2 acquisition software
Max Number of channels	Up to 8
Antenna Frequencies	200-600 MHz
Positioning	Metric wheel and/or GPS interface
Collection Speed	3.77 m/s in full configuration (8 channels)
Max. Scan Rate	4760 Scan/s
Battery operation time	>8 h
Weight	58 kg full configuration (i.e, 4 Antennas)
Size on ground	200 cm x 60 cm (full configuration)
Survey path width	Up to radar scans 52 cm each
Wireless connection	Available
Protection Class	IP65

Table 4. Hi-Mod specifications.

Fig. 55. The HI-Mod II in Villa Rufolo. Photo by Pino Izzo.

[1] Acknowledgments are due to Alfonso Santoriello and Felice Perciante of the *Dipartimento di Scienze del Patrimonio Culturale* of the University of Salerno.

The analysis with high frequency georadar allowed to investigate and analyze the situation below the current ground level, reaching a maximum depth estimated between 2.5 to 3 meters. The *Sala dei Cavalieri* was selected as a suitable area for the analysis. The investigated area is characterized by the presence of historical buildings and landscaping works, which allowed to identify multiple reflections in the underground referable to the presence of pipes or sub-services sometimes masked by natural elements such as roots, or metallic such as gratings, under the acquisition plane. A total of 45 radargrams were carried out over a total length of about 500 m of measurements, covering an area of about 160 m^2. The survey led to evidence of reflections clustered in areas of interest, distributed along the investigated path, and mostly concentrated in the first 0.1 - 2 m from the ground plane. At the same time, it is observed that the area adjacent to the historical elements, *Torre Maggiore* and *Sala dei Cavalieri*, is characterized by a different compaction of the material compared to the surrounding environment or by clusters of reflections chaotically distributed in the underground. The latter could lead to think of an area that, although altered over time, could still preserve buried historical elements (Fig. 56).

3D GPR imaging are an excellent tool for non-invasively detecting and interpreting archaeological remains. Intuitive understanding of geophysical data by archaeologists or historians can be very useful, as well as cost and time saving, for the planning of most archaeological excavations, and this purpose is achieved if the data are accurately positioned during a sufficiently dense acquisition and then properly processed and visualized in three dimensions. To contribute to the analysis of the chronology of Villa Rufolo, this tool has made it possible to interpret not only the visible, but also the invisible, or that which can be buried.

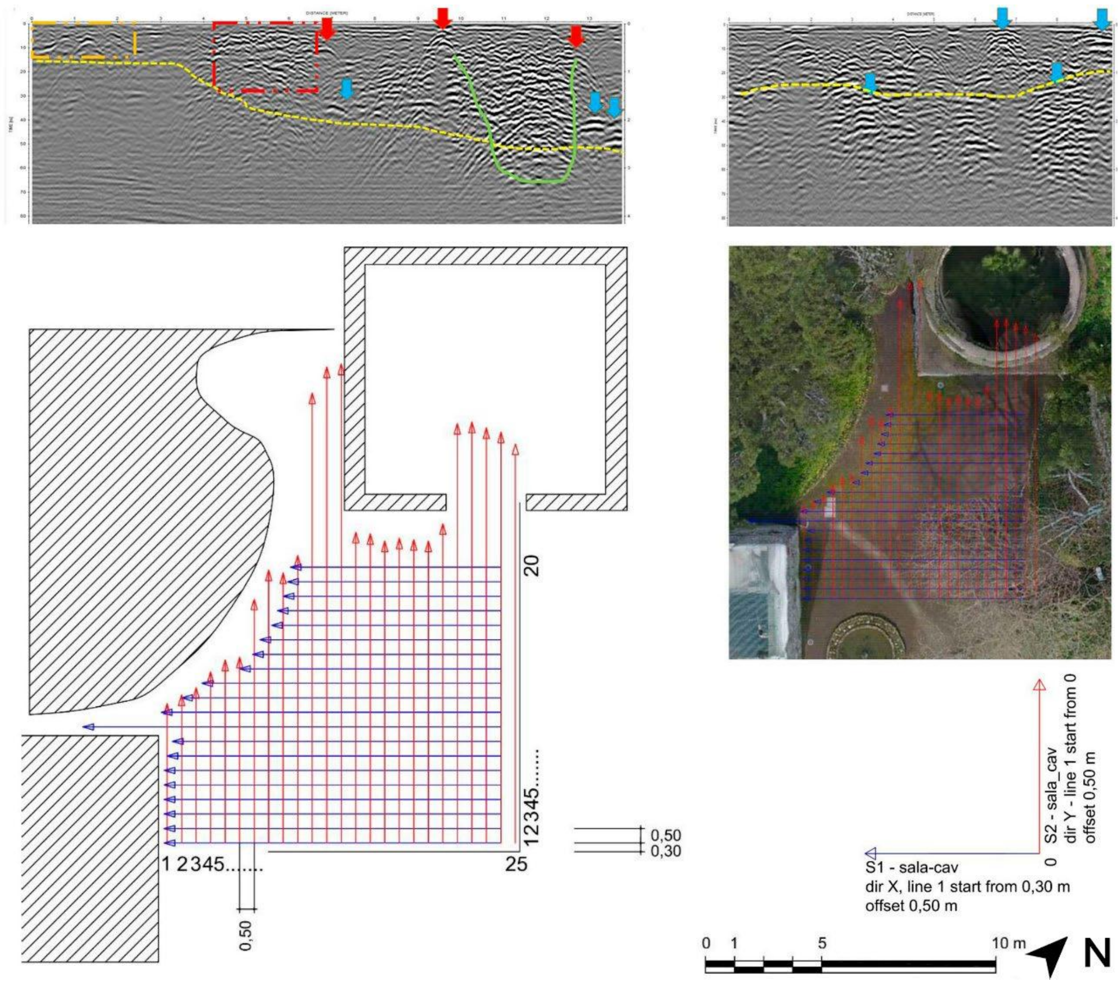


Fig. 56. GPR data acquisition scheme with profile identification and radargrams.

SLAM-BASED MOBILE MAPPING

To complete the digital survey of Villa Rufolo, it was necessary to record the interior spaces as an additional feature. Just as the photogrammetric technique with UAV was preferred for the exterior, for the complicated interior space, the dynamic laser system has been considered the most suitable solution. In 2019 the survey campaign was carried out with Simultaneous Localization And Mapping (SLAM) technology. It has been possible to test this technology using an instrument purchased by a company in Naples[1]. In particular the instrument used was the ZEB1, introduced by GeoSLAM in 2013 (Table 5). It has a spring-mounted sensor head and a data acquisition rate of 43,200 points/s at a maximum range of 30 m, with an accuracy of 3-5 cm. Villa Rufolo, characterized by its articulated and complex spatial geometry, mainly due to its numerous temporal stratifications, therefore becomes an optimal case study to test the capabilities of this technology (Fig. 57).

Maximum range	30 m
Relative accuracy	± 0.1%
Scan points per second	43,200 points/s
Scan range noise	±30 mm
Laser safety classification	Class 1 Eye-safe per IEC 60825-1:2007 & 2014
Laser wavelength	905 nm
Operating temperature	0 °C to 50 °C
Protection Class	IP54
Power supply	14.8VDC ~ 1.5A
Weight	Scanning head and data logger ~ 1.50 kg
Battery life	Approx. 3.5 hours continuous use

Table 5. GeoSLAM ZEB1 specifications.

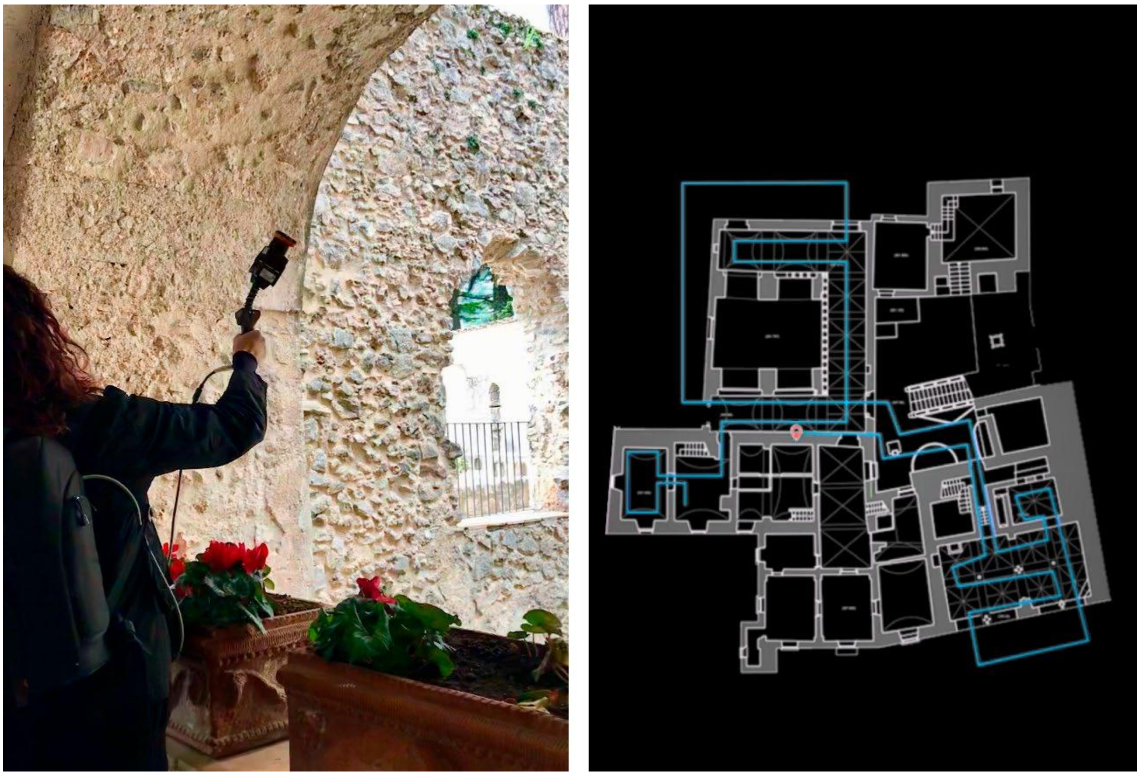


Fig. 57. The ZEB1 in Villa Rufolo and one-path definition.

[1] Acknowledgements are due to Mariella Danzi.

Survey planning

The ZEB1 is the first mobile mapping system produced by GeoSLAM, this instrument, combining motion sensors with observation sensors, can integrate and merge heterogeneous data streams through special algorithms, guaranteeing three-dimensional digital reconstruction of the surveyed areas. It is equipped with a class one 2D laser profilometer, placed on top of a spring whose oscillations guarantee a three-dimensional acquisition. The laser is synchronized with an IMU control unit whose data flow, suitably processed, allows the recording of consecutive spatial profiles, with a relative accuracy of ± 0.1% (Gollob et al., 2020).

Systems that use SLAM algorithms to generate three-dimensional surveys require special attention when planning acquisitions. In fact, more than any other solution, the quality of the raw data based on the SLAM approach depends to a large extent on how the acquisition campaign is carried out. It is important to carefully inspect the site of interest beforehand to identify critical areas and remove any obstacles in the way. The SLAM systems require auto intersection of trajectories to ensure proper redistribution of accumulated errors (Fan et al., 2020). In order to have a strict control of propagation and error compensation, a procedure has been defined that includes a precise survey phase. The trajectories have been designed in such a way as to guarantee horizontal and vertical self-intersection, forming closed loops that always start and end at the same point. The initialization procedure must be performed on a flat surface, and the arrival point must be in the same position as the starting point. This is essential for the alignment and control of the point cloud; the trajectory and loops must be planned according to the configuration of the environment, considering transition zones and poorly referenced environments. The SLAM system originates from the iterative alignment of the extracted profiles that are based on the space's own attributes, therefore, the space itself functions as a reference.

Data capture

With these concepts in consideration, the acquisition campaign is organized in five loops. It is necessary to ensure self-intersections within the individual loops, almost always developed on several levels, as well as between the different loops, in order to simplify and optimize the post-processing phase. At least one loop must be closed, although it is advisable to plan routes with several self-intersections. The acquisition campaign in Villa Rufolo was organized as follows: the first loop includes the management offices on the entrance level (where the initial point was set, conveniently facilitating the survey) and the auditorium; the second loop covers the entrance level, the gardens and the central courtyard; the third loop covers the warehouse and the rooms closed to the public on the entrance level, as well as part of the garden; the fourth loop takes place in the subway level, passing through the lower part of the *Chiostro Moresco* to the exhibition rooms of the present theater; the fifth and last loop covers all the museum rooms, connecting with the auditorium and ending the loop in the offices, the starting point of the first loop. The 3D data are acquired by simply walking through the spaces and holding the device in one hand. To ensure the quality of the survey it is necessary to avoid moving people or objects. Each data set has to be acquired in an average time of no more than 20 minutes. The acquisition time is considered to be the sum of the few minutes needed for initialization and closure with automatic preprocessing and storage of the data in the integrated memory. The instrument proved to be advantageous for its extreme practicality, allowing us to acquire about 30 environments in a single day, covering an area greater than 1,500 m^2. The complete recording of the 5 loops was carried out in less than 2 hours. Most of the time was used to adequately plan the survey.

Data processing

The ZEB1 device acquires the local scene approximately once per second. Local views of the scenes, obtained by rocking the instrument, contain the position and normal direction of each recorded element. By matching pairs of surface elements acquired at different times, the trajectory is estimated through the relationship between the surface geometries. The data have been processed by GeoSLAM using its SLAM process in the Cloud. Then, the derived 3D point clouds in LAZ format were processed in Cloud Compare software to align and merge them. After a first manual transformation for rough alignment between consecutive scans, a finer registration was performed with a traditional iterative closest point (ICP) method. The maximum root mean square (RMS) value in the registration of consecutive scans was approx. 1.95 cm. The final 3D point cloud fused with this method contains about 11,000,576 points (Fig. 58).

Results

Indoor spaces are favorable for better performance of the ZEB1 system. The use of the GeoSLAM mapping device in the interior spaces of Villa Rufolo is validated as an appropriate approach in terms of time, operability, and 3D reconstruction. Mobile mapping systems are a solution characterized by speed, flexibility, and acceptable quality of results. However, there is currently no established literature on their application, and even less so in the field of Cultural Heritage. It is a technology that makes it possible to construct a map of an unknown environment and simultaneously determine the position of the instrument within that same environment. To achieve these objectives, information from multiple sensors is fused, a motion sensor, an Inertial Measurement Unit (IMU) that allows us to return a point cloud, with a tolerable level of accuracy and precision, and in an incredibly short time. SLAM technology recovers at least 300% of the time taken to survey the same space with static TLS technology. The latest developments in the field of topography are, nowadays, related to the use of low-cost portable LIDAR instruments and to new methodologies such as SLAM which are very promising: probably less accurate but very productive in terms of acquisition and processing time, so they are considered suitable tools for HBIM purposes (Chiabrando et al., 2017). In this Thesis it will be experimented the new SLAM-to-BIM approach (HBIM - First modeling approach).

Fig. 58. SLAM point cloud of Villa Rufolo.

TLS-BASED RECORDING

However, during the analysis phase of the point cloud of the interiors, it was determined the need to acquire information related to certain areas inaccessible during the SLAM survey campaign. Therefore, in order to complete the survey of the interiors and obtain a complete point cloud that would allow us to analyze the spatial geometry of the complexity of Villa Rufolo, it was necessary to extend the incorporation of acquisitions using a TLS. These new acquisitions also serve as a georeferenced base for the control of the SLAM survey (Fig. 59).

Maximum range	130 m
FOV	360° x 300°
Scan points per second	976,000 points/s
Scan range noise	± 2 mm
Laser safety classification	Class 1 Eye-safe per IEC 60825-1:2007 & 2014
Laser wavelength	1550nm
Operating temperature	5°C to 40°C
Weight	5.2 kg
Dimensions	240 x 200 x 100 mm
Battery life	4.5 hours continuous use
Protection Class	IP54

Table 6. Faro Focus^{3D} x130 specifications.

Fig. 59. The Faro Focus^{3D} x130 in Villa Rufolo.

The instrument used, the Faro Focus^{3D} x130 (Table 6), with GPS integrated, has been configured to have a resolution of 6 mm at 10 m. Regarding the quality of the acquisition, for each point in the cloud, three measurements are taken to define the distance to the station as the average of the previous measurements. This allows to integrate the data in the best possible manner to the SLAM point cloud.

The survey planning was necessary to define the positions of each TLS station, so that the coverage of the whole area, with the required spatial resolution, could be guaranteed. Five areas were surveyed that would complete the internal survey and serve as the basis for georeferencing and integration with the point clouds acquired by the previous technologies.

First of all, scans were acquired in the garden, replicating the area surveyed during the *Balnea* survey campaign, thus ensuring a better integration of all the data. Next, the lower rooms of the *Torre Maggiore*, the area of the medieval oven, the library and finally the upper offices were surveyed, extending the acquisitions even to the roofs of Villa Rufolo.

A total of 20 TLS scans were acquired. With the indicated characteristics and an average scan time of approximately 12 minutes, the TLS acquisition campaign lasted approximately 5 hours.

These data have been used to create a reference network, which is indispensable for an evaluation of the SLAM data quality. The point clouds are characterized by a high degree of overlap and, for this reason, are registered using a global fitting procedure, performed from a top view-based pre-registration. Given the set of scans, the algorithm searches for all possible connections between pairs of point clouds with sufficient overlap. For each connection, a pairwise ICP is performed and the best matching point pairs between the two scans are retained. A final nonlinear minimization is run only between these matched point pairs from all connections. The overall registration error of these point pairs is minimized, having as known variables the positions of the scans. Finally, it is observed the SLAM point cloud integrated with the TLS acquisitions (Fig. 60).

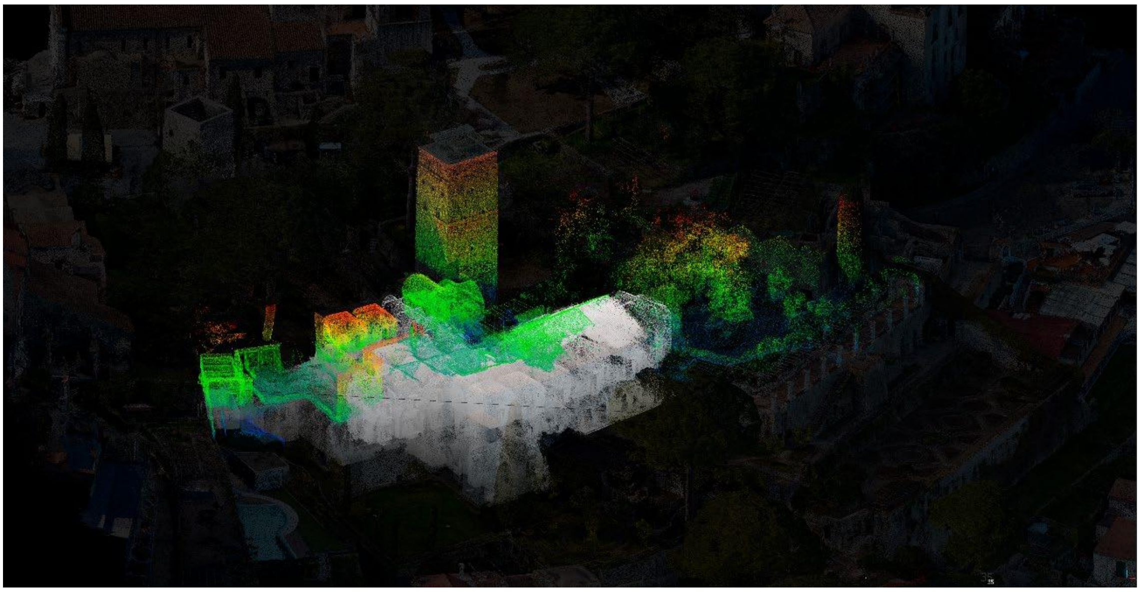


Fig. 60. SLAM & TLS point cloud of Villa Rufolo.

SLAM, TLS, UAV & GNSS INTEGRATION

Aligning in the same reference system data acquired with different techniques, using different instruments, at different times, and carried out by different operators, represented a real challenge. All the surveys carried out in these three years of collaboration with Villa Rufolo have been compensated and integrated with the use of open-source software. The challenge has been to bring together information of different nature in the same reference system. The data from GPS, total station, photogrammetry, static and dynamic laser scanner; achieved through this integrated survey help to overcome the limitations inherent to each technical specification. This was made possible by optimizing data acquisition and processing.

In the case studied, the UAV system allowed the photogrammetric reconstruction of the exteriors, also ensuring the contextualization of Villa Rufolo, with a high precision guaranteed by the integration of GNSS data. On the contrary, for the interiors, due to the presence of complex and narrow spaces, a dynamic technique was chosen, in particular, the SLAM approach was preferred to the stationary TLS systems, allowing a significant reduction of the acquisition times, while guaranteeing an accuracy compatible with the survey purposes. Finally, to control the metric data and support the dynamic survey, TLS acquisitions were performed, obtaining high accuracy results.

The UAV, SLAM and TLS point cloud alignment methodology has provided the identification of homologous points on the exterior facades, common to the surveys. The first solution is in the 3D point cloud with measured coordinates (xyz) as references. The evaluation of the metric quality of the alignment can be expressed by the RMS value at many homologous points. A more effective solution for aligning point clouds is generally the control of deviation errors by the ICP algorithm, between recognizable characteristic elements of the reference surface, the photogrammetric cloud and in the comparative surfaces, the SLAM and TLS based point clouds, and finding the best possible match between them through the ICP algorithm. Another manual visual alignment process has been performed with movement, rotation and scaling parameters needed to match the SFM data with the TLS and SLAM data. As a result, the 3D integrated point cloud was created with the actual size of the surveyed object (Fig. 61).

Once the three-dimensional data set is available in the same reference system, it is possible to manage the huge amount of data while ensuring an adequate level of detail where needed. The application of active and passive optical sensors for the digitization and documentation of Villa Rufolo highlights a fundamental point: each instrument or method is defined by peculiarities that make it unique, both in terms of acquisition mode and type of data provided. This strong characterization limits the exclusive use of certain techniques, even more so considering the complexity of the relevant conditions of the case study (Guidi & Frischer, 2020).

This requires an analysis on the range of performances that can be achieved by the single instrument. For this reason, integration between different systems is appropriate, in order to obtain the best result in terms of individual data accuracy, overall accuracy and process optimization. The model produced is characterized by a variable resolution, multi resolution point cloud, where the metric data is consistent with the geometry contained in the context of interest. The project seeks a broad understanding of the object of study, with a survey that is not limited only to the knowledge of geometry and dimensions, but consists of an extended knowledge process where formal, compositional, constructive, structural, and historical information is acquired. The opportunities offered by the integration of these modern digital surveying techniques allow to obtain new products that not only improve the metric data but are also effective for representation and visualization purposes. The generation of an accurate 3D model with the integration of active and passive sensors is an infographic product for the development of potentially sustainable documentation for the conservation of architectural heritage.

This integration allows to virtually reconstruct places of historical interest to document, and at the same time, provide a tool to interpret the dynamics of transformation of architectural objects. Being an effective tool not only at the level of visualization and communication of heritage, but also as a real analysis tool (Figs. 62, 63). The digital processing of the data acquired with different survey techniques will update the documentation, proposing possible interventions for the enhancement of the case study. The innovation will take place in terms of, documentation, with the generation of graphic representations in 1:50 architectural scale of the current state of the case study in order to update the documentation of the direction of Villa Rufolo (Figs. 64, 65); visualization, all the information will be accessible in a 3D virtual space; and dissemination, through the creation of online material that will allow widespread virtual visits. This tool allows to reveal to the specialists of the sector, as well as to the community in general, what is still hidden, in the form of a virtual model. It is a different way of representing the space, even for those who do not know it, it is an effective plan for cultural promotion.

The objective is to produce an instrument of diffusion that communicates the history of the object of study, with a graphic-expressive language, but at the same time, simplified; effective both for the correct historical-architectural interpretation, with an adequate historiographic and scientific rigor as a fundamental line, but, above all, effective also for a wider public. Through these new ways of highlighting and making architecture known, the aim is to involve a wider range of users, to encourage, sensitize and motivate them to take an interest in the historical object. Technical information on heritage must be interpreted, that is, it must be 'adapted' to the non-expert public. Interpreting heritage is therefore a way of communicating so that the public understands and values Cultural Heritage (Figs. 66, 67).

These technologies, in fact, if on the one hand they facilitate understanding because they produce results using the new languages of communication, on the other hand, they improve the study of the experts thanks to the precision of the data they provide. The integrated point cloud becomes a powerful tool at the service of the community to understand the heritage, but also to extract an infinity of useful information in multiple fields of Civil Engineering and Architecture. This multidisciplinary and technological vision of heritage protection aims to be a key digital tool in the current efforts of conservation, study, and enjoyment of Cultural Heritage.

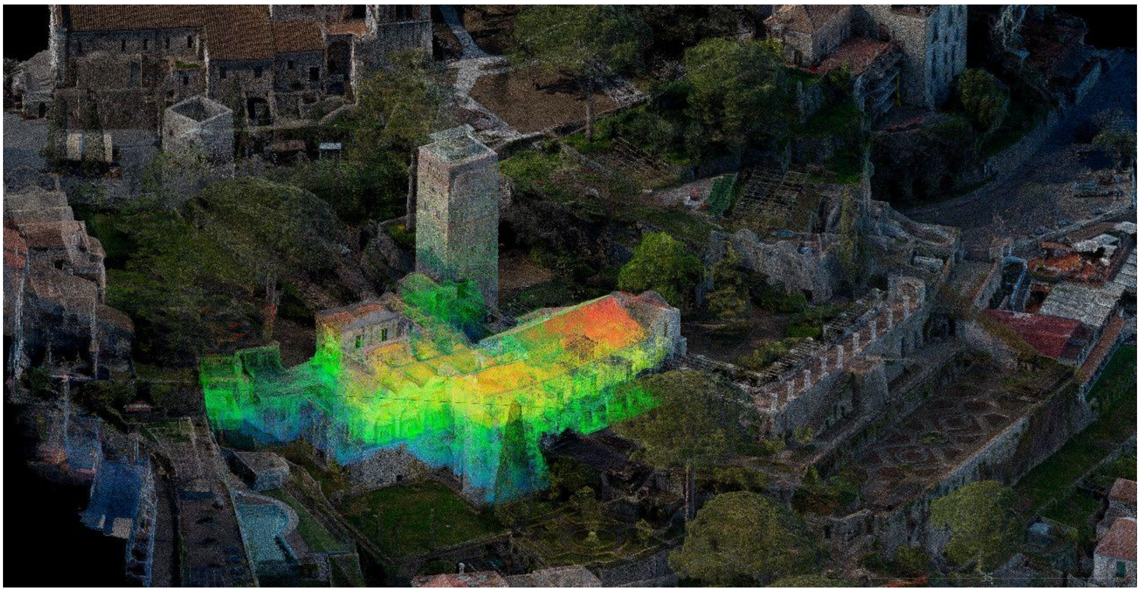


Fig. 61. SLAM, TLS, UAV & GNSS point cloud of Villa Rufolo.

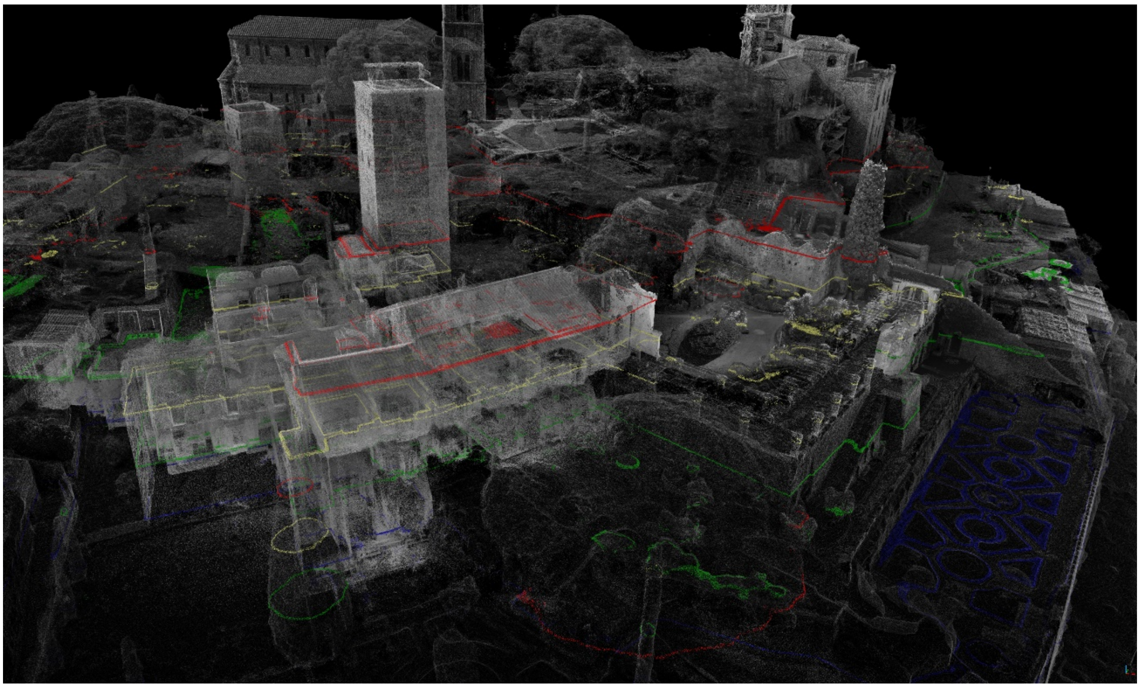


Fig. 62. Integrated point cloud of Villa Rufolo.

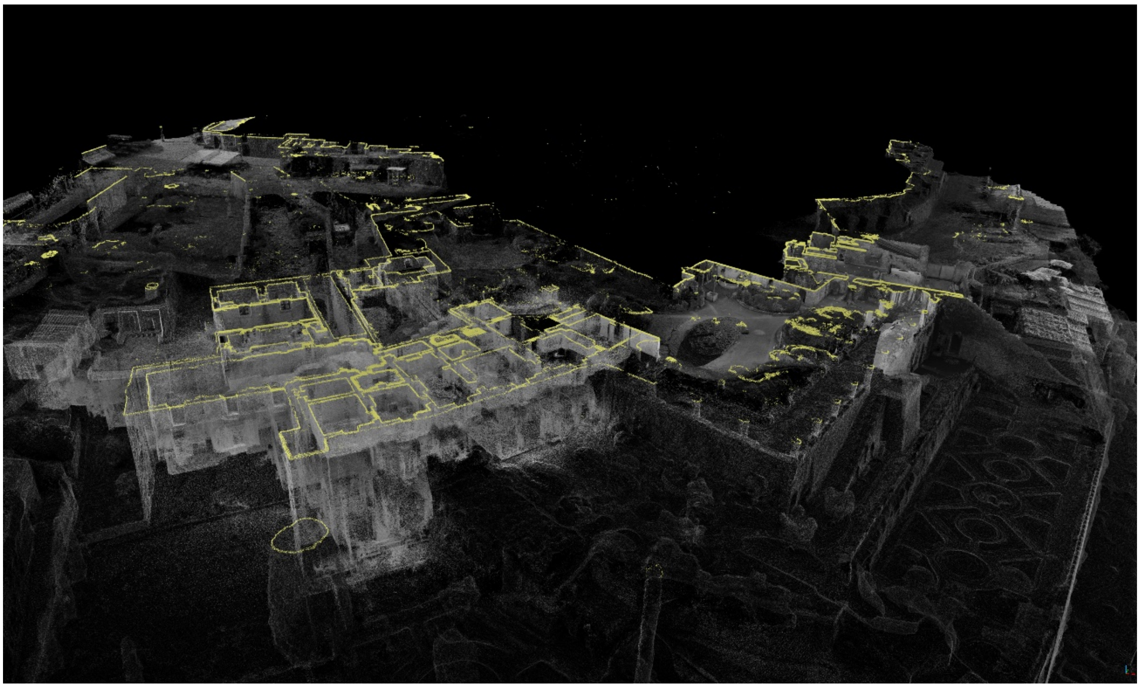


Fig. 63. A 3D section of the integrated point cloud of Villa Rufolo.

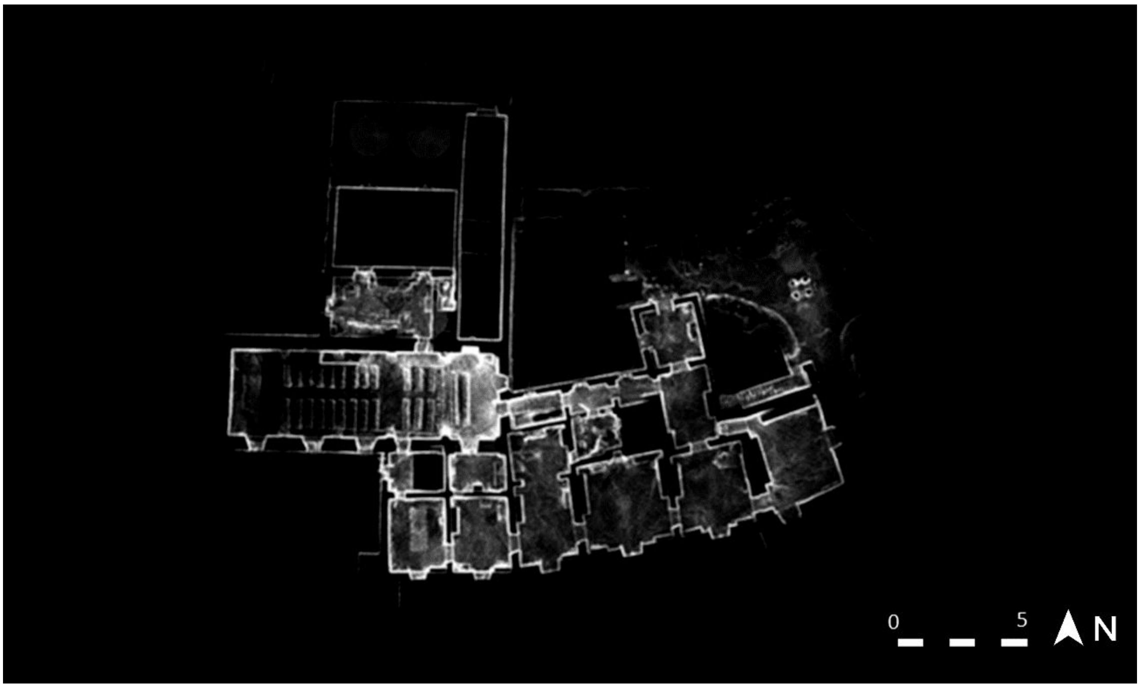


Fig. 64. Orthographic projection of point cloud of Villa Rufolo.

Fig. 65. Comparison between Villa Rufolo plan of 2008, in red, and plan of 2019, in grey.

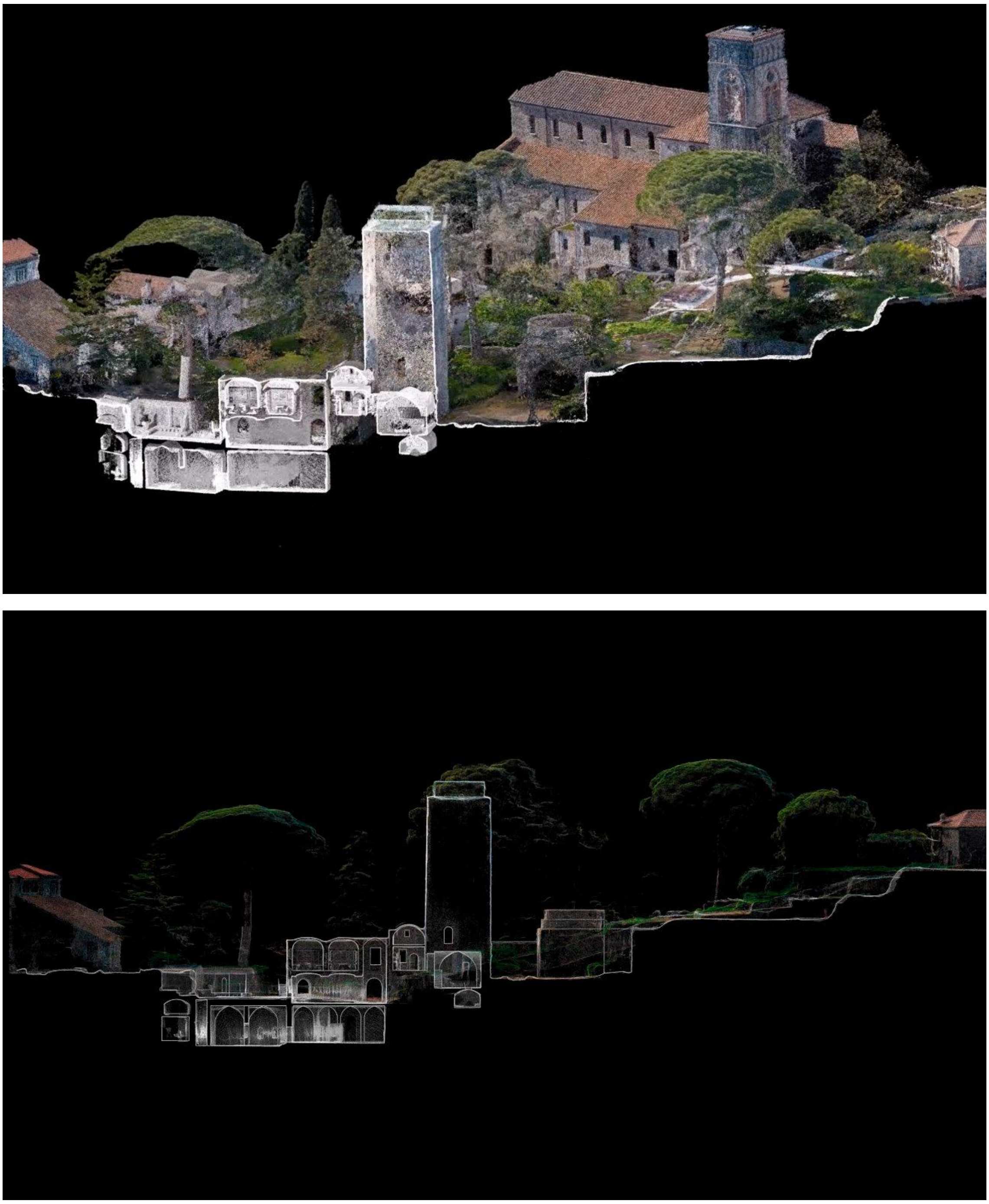


Fig. 66. Point cloud and section of Villa Rufolo.

Fig. 67. Point cloud and section of Villa Rufolo.

BUILDING INFORMATION MODELING

In the history of architecture and engineering, activities such as design, study or analysis have taken advantage of different instruments to represent and describe the reality. In either case, when going 'from the design to the constructed building' or vice versa 'from the physical building to its in-depth analysis', reality is too complex to be described as it is, and needs to be simplified, decomposed, schematized, i.e., modeled.

The model is precisely an abstraction of reality, a simplified representation derived from the identification of rules and standards that represent the essence of reality. A correct model, then, does not distort reality, but recognizes its characteristics and includes those rules capable of accurately represent reality assuming a proper degree of simplification.

When referring to modeling strategies, it is impossible not to consider the BIM methodology. Building Information Modeling (BIM) is currently one of the most advanced technology for the design, management, and documentation of buildings. It is indeed a process based on an intelligent 3D model, that can be located in a cloud platform, opening up possibilities for collaboration among a multidisciplinary community and creating favorable synergies, such as the adoption of innovative solutions for a more efficient repository of digital resources. BIM, nowadays, is at the heart of digital transformation, also known as the fourth industrial revolution, in the AEC sector (Fig. 68).

BIM, as an abbreviation for Building Information Modeling, is known all over the world. However, even today, it is difficult to find a common definition of what exactly BIM is, as many organizations tend to define BIM according to their needs, and according to the purpose of their work. For example, Chuck Eastman, one of the leading researchers in the BIM field, defines it in his BIM Handbook, Sacks et al., (2018), as, "a modelling technology and associated set of processes to produce, communicate and analyze building models"; Building SMART International, on the other hand, defines BIM as, "a new approach to being able to describe and display the information required for the design, construction and operation of constructed facilities". On the contrary, the U.S. Building Information Modeling Standard defines BIM as, "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder".

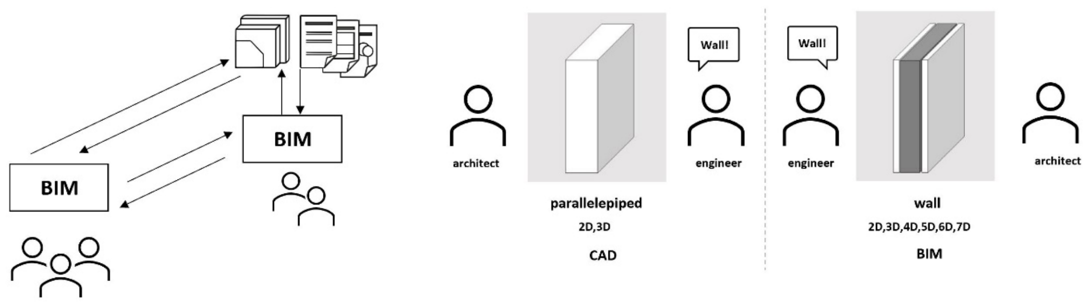


Fig. 68. Building Information Modeling concept.

Another definition is provided by the internationally recognized National Building Specification, as BIM "is a process for creating and managing information on a construction project across the project lifecycle. One of the key outputs of this process is the Building Information Model, the digital description of every aspect of the built asset. This model draws on information assembled collaboratively and updated at key stages of a project. Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset".

While understanding Building Information Modeling as a process plays an important role, it is also necessary to understand what the specifics of the Building Information Model are, given the need to differentiate between the process of creating the model and the model itself. A suitable definition of Building Information Model was provided by Borrmann et al., (2018): "a Building Information Model is a comprehensive digital representation of a built facility with great information depth. It typically includes the three-dimensional geometry of the building components at a defined level of detail. In addition, it also comprises non-physical objects, such as spaces and zones, a hierarchical project structure, or schedules. Objects are typically associated with a well-defined set of semantic information, such as the component type, materials, technical properties, or costs, as well as the relationships between the components and other physical or logical entities". The definition of the Royal Institute of British Architects can be used as well: "a Building Information Model is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming, a reliable basis for decisions during its life cycle from inception onward".

Regarding the context of this thesis, it should be noted that in Europe, according to the NBS National BIM Reports, more than the 80% of the buildings were built before 1990 and, the most part of them, do not have construction documentation in a BIM format; even less, in the case of Heritage Buildings.

In recent years there has been a growing diffusion of BIM methodology, mainly thanks to the introduction of regulations and standards that impose, or at least regulate, its use[1]. In Italy, the application of the Italian National Unification Agency (UNI) 11337:2017 standards is the foundation of the national strategy for the digital management of information processes, since the publication of the new contract code (Legislative Decree 50/2016), which provides for a progressive adoption of BIM.

For the purposes of this thesis, Building Information Modeling will be defined as an information management method for construction projects based on the consistent use of digital models

[1] In UK can be mentioned the Royal Institute of British Architects (RIBA); UK BIM Task Force Group; National British Standard (NBS); BSI 1192-1:2007, BS-PAS 1192-2:2013, BS-PAS 1192-3:2014; NBL National BIM Library; BIM Toolkit; CIC BIM Protocol:2013; COBie - Construction Operations Building Information Exchange. In USA can be mentioned the American Institute of Architects (AIA); National Institute of Building Sciences - buildingSMART alliance - (NIBS); US chapter of buildingSMART International (BIMforum); US Army Corps of Engineers (USACE); AIA Contract Document G202-2013; Building Information Modeling Protocol Form; AIA E203–2013; Building Information Modeling and Digital Data Exhibit; AIA G201–2013, Project Digital Data Protocol Form; National BIM Standard United States – V3:2013 (NBIMS-US); National CAD Standard United States – V6:2014 (NCS-US); BIMforum LOD specification (2013-2016); National BIM Guide for Owners; BIM Project execution Planning Guide V2.1:2011; USACE BIM contract requirements (UBR). In Italy, the UNI (Italian national unification) has published parts 1, 4 and 5 of the national standard UNI 11337, which deals with digital management of information processes in construction and, specifically, deals respectively with: models, elaborates and information objects for products and processes; evolution and information development of models, elaborates and objects; information flows in digitized processes.

throughout the entire life cycle of an existing building. The models include both the 3D geometry of the building components, as well as a broad set of semantic information, including function, materials, and relationships between objects.

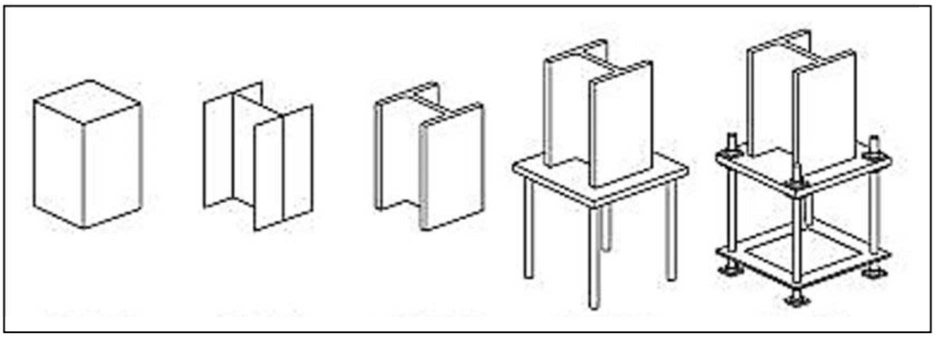
BIM is a new method, which is constantly growing, developing, and changing. For BIM processes, it is important to define some of the most used concepts, considering that many definitions can be incorporated or modified over time:

LOD: Level of Development

For the definition of LOD, the Italian regulation, in analogy with the United States and United Kingdom reference standards, specifies that the level of development of digital objects is defined as a sum of the level of development of its graphic and non-graphic attributes. The LOD defines the quantity and quality of information content and is functional to the achievement of the objectives of the process phases, i.e., it depends on the intended uses and the purposes behind the model definition.

According to BIM standards, in order for the overall data and information related to an object to be considered in the definition of a given LOD for a specific object, their unique, even non-parametric/relational, connection to the object itself must be guaranteed. These data and information can be either external to the object itself or distributed in several different information models and elaborations (graphical, documental, or multimedia), or in attached digital information sheets.

The LOD is classified with a numbering in the United States (100, 200, etc.) and in the United Kingdom (1, 2, 3, etc.). In Italy, instead, it is classified through letters in alphabetical order from A to E (Fig. 69). Furthermore, the Italian regulations incorporate LOD classifications applicable to the restoration of Cultural Heritage: LOD F *(oggetto eseguito – executed object)*, which is required to document the as-built including management and maintenance plans; and LOD G *(oggetto aggiornato – updated object)*, which represents the evolution of the object during its useful life, and provides information on maintenance, restoration, interventions; the LOD G also relates to the widespread concept of digital twin.



LOD 100	LOD 200	LOD 300	LOD 350	LOD 400
LOD 1	LOD 2	LOD 3	LOD 4	LOD 5
LOD A	LOD B	LOD C	LOD D	LOD E
Symbolic	Conceptual	Generic	Specific	Construction

Fig. 69. LOD grades as defined in AEC BIM Technology. US UK & IT standards.

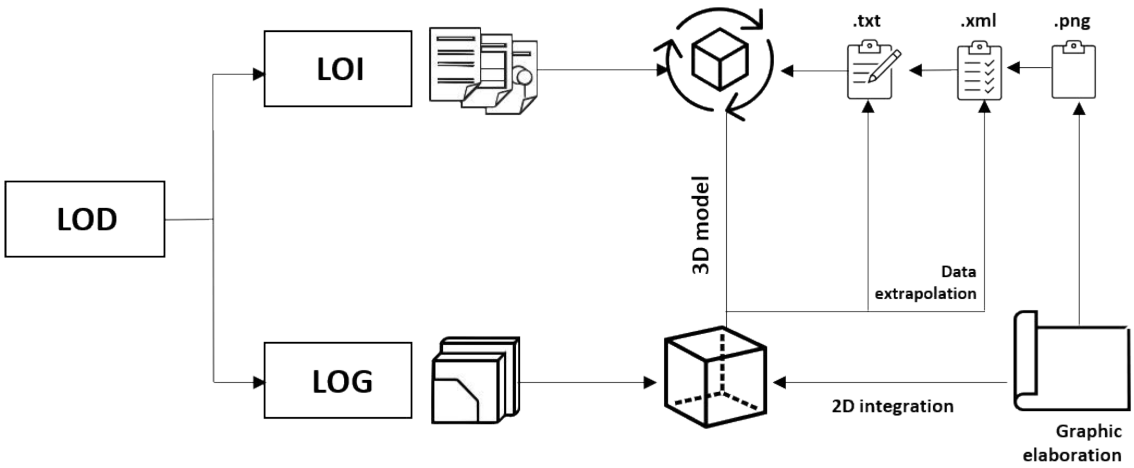


Fig. 70. Level of Development, Level of Information and Level of Geometry. Pavan A., 2020.

Therefore, we can say that the level of development (LOD) is given by the sum of the level of geometry (LOG) and the level of information (LOI) (Fig. 70). The LOD is related to the modeling objectives and determines all subsequent steps, from technique selection to model creation, because of its strong influence on data quality, data volume, and processing effort.

LOD = LOI + LOG

LOI: Level of Information

It refers to infographic data, texts, documents, tables, etc., i.e., the information derived from a multidisciplinary approach. In short, any type of documentation that can provide information on any phase of the object's life cycle, not only related to the object itself, but also to the context in which it is inserted.

LOG: Level of Geometry - also known as Level of geometrical Detail (LoD) in Italian standard

It mainly refers to the graphical information of a BIM model and the degree of geometric accuracy, which can be related to the required scale of the final drawings and, therefore, directly to the design phases.

The use of BIM-oriented software offers considerable advantages in terms of time and cost savings. The drawing of a disproportionate number of lines, polylines and various geometric shapes is avoided. It is a methodology based on objects with specific properties and information (materials, costs, thermal capacity, maintenance, etc.). Floor plans, elevations and sections can be easily produced, being simply different views of the same object, thus drastically reducing the number of errors in the project. Any change in the BIM model affects all views and graphs generated. It is, in all respects, a centralized project.

Moreover, the strengths of BIM lie in standardization: from the definition of the building parts to the processes; if it is possible to enhance the efficiency of the construction process through recurrence, BIM is the tool to optimize it. However, the standardization, which makes BIM so efficient for new construction projects, becomes difficult to achieve when it comes to Cultural Heritage. For the said reasons, both the scientific community and the AEC industry are currently experimenting with the use of BIM for existing buildings.

Integrated and centralized design, from modeling to planning, from collaboration to management, are concepts at the basis of BIM, backed by consolidated regulations and extensive standardization works provided by, e.g., the International Framework for Dictionary Libraries and the Delivery Manual. At the European level, it is important to mention the European Committee for Standardization (CEN) and the UNI 11337:2017 standard in Italy. BIM is transforming the construction sector. *But how is it possible to extend these standards also to historical architecture?*

Due to the complexity and uniqueness of a historic building, and the variety of projects that affect it, such as conservation, adaptive reuse, preventive maintenance, management, interpretation, documentation, and research, the application of BIM in the sector of Cultural Heritage still raises a lot of questions.

BIM applied to heritage, or HBIM (Historic Building Information Modeling) was first mentioned by Murphy et al., (2009) and defined as “a novel solution whereby interactive parametric objects representing architectural elements are constructed from historic data, these elements (including detail behind the scan surface) are accurately mapped onto a point cloud or image-based survey”. Since then, the term has been expanded to include a broader heritage concept by Brumana et al., (2013), recognizing a more complex set of historical and aesthetic values, and the involvement of multiple interested disciplines.

However, at present, there is no established tool for modeling the Cultural Heritage, and HBIM technology is at an early stage compared to BIM. Therefore, its application is an innovative challenge, increased by the difficulty of finding information related to the specific Cultural Heritage, the poor adaptability of the software to complex geometries, the absence of historical libraries of parametric objects and the lack of experience in the application of BIM to Cultural Heritage.

For HBIM application, it is first necessary to organize a heterogeneous set of data related to the selected case study, i.e., metric, formal, historical, stratigraphic information, on the state of conservation, on the characteristics of the materials, etc. This implies a work of integration of the collected information and the need to readjust the material in relation to the objectives of the modeling and the specificity of the software to be used. Therefore, depending on the material collected and on the project objectives, there are different approaches to HBIM modeling (Fig. 71).

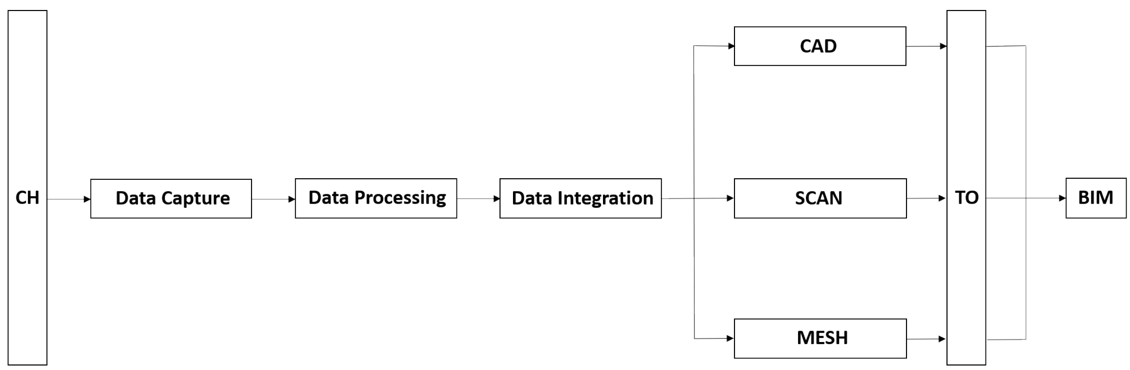


Fig. 71. Outline of the modeling process.

According to Dore & Murphy (2017) historical BIM is proposed as a new system for modeling historical structures that begins with the remote collection of surveyed data. Georeferenced data sets, such as point clouds, can be integrated into BIM to be used as the basis for modeling. In regards, it will be necessary to clarify another important BIM concept.

LOA: Level of Accuracy

It represents the required accuracy of the surveyed element (measured accuracy) and that of the reconstructed element (represented accuracy). According to the United States Institute of Building Documentation[1] (USIBD), it is organized in five different levels, ranging from LOA 10 to LOA 50, which correspond to increasingly narrow intervals for the measurement to be considered acceptable.

The advantages of using 3D surveyed data sets (e.g., point clouds obtained employing the previously presented techniques) for BIM are significant. Large volumes of high-resolution data covering all visible surfaces of the object (possibly even with color information) provide a reliable basis for creating native 3D geometry in a BIM environment. The term Scan-to-BIM is used to describe these workflows, which represent a reverse engineering process that uses the point cloud as a reliable metric basis for HBIM modeling and aims at reconstructing a constantly updatable model. Its LOD can be implemented and upgraded according to the project requirements. There are others 'more conventional' approaches to creating parametric models based, e.g, on CAD drawings. However, the level of geometrical detail (LOG or LoD) that can be achieved using the CAD-to-BIM method is generally less than that the one obtained with a Scan-to-BIM approach. There are other approaches, certainly more automated, such as Mesh-to-BIM, but, even if the results are closer to the object in terms of LOA, at the same time, the technique sacrifices the overall LOD due to the low LOI and the inexistent parametrization of the components.

HBIM is designed to support knowledge, management, and intervention actions on architectural heritage, which are the basis of its preventive conservation. HBIM offers the possibility to organize all the information related to that historic building (such as archival drawings, photographs, written sources, recordings, or any other type of digital/digitized file) in a spatial hierarchy. The information can be linked to spaces or building components that together constitute the complete 3D parametric model of the historic building. BIM then provides a database of all the information related to it, which can be intelligently consulted and used for research, conservation, and management purposes. It will allow us to understand the evolution of the model over time and, therefore, to rethink the current understanding about history, maybe exploring the buildings in a completely new way, i.e., virtually and/or from a distance.

The complexity of Villa Rufolo, with its irregular geometries, non-homogeneous materials, variable morphology, undocumented changes, and various stages of construction, shapes the specific approach chosen to model it. In the present case, two different modeling approaches have been experimented, both implementing the Scan-to-BIM process. The first one employed mostly masses, to obtain a more geometrically accurate model, thus more faithful and closer to the physical object. Whereas, the second approach, in which it was preferred to parametrize as much elements as possible, resulted in a more simplified model, although way more complex to create; this kind of model is therefore capable of letting us to interpret the complexity of reality, to study its peculiar characteristics and to, ultimately, code the reproducibility of the elements that create the whole. In the scientific community, these two approaches are still intensely debated. Although it should be noted that the strengths of BIM are based on the attempt at standardization, which in the case of HBIM must go through the definition and optimization of knowledge processes.

[1] https://usibd.org/ (last accessed March 2021).

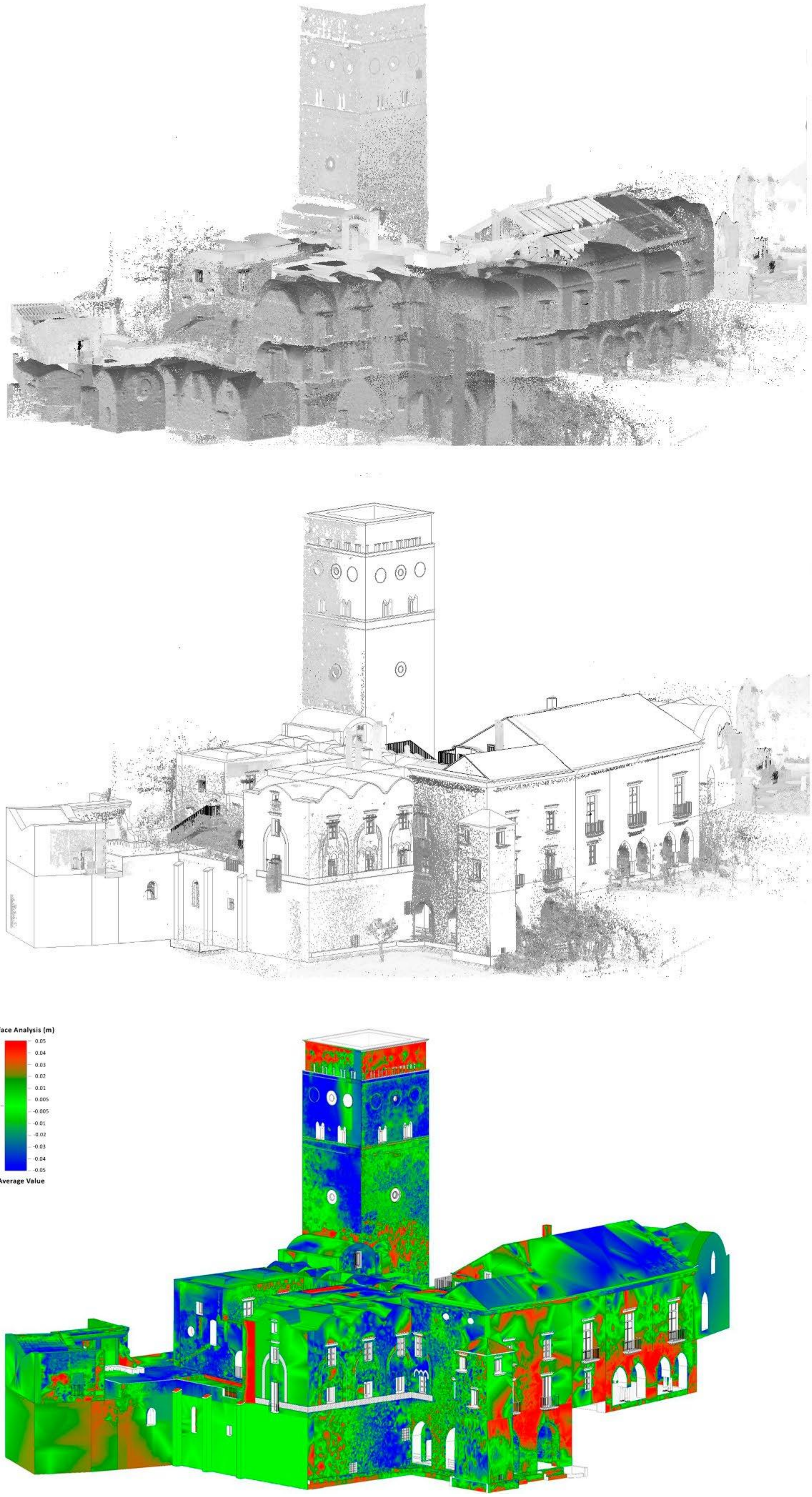


Fig. 72. Slam-to-BIM. Cotella V., 2020.

HBIM - First modeling approach: SLAM to BIM

Starting from the survey of the interiors of Villa Rufolo, carried out as described in the previous chapters with SLAM technology, the first modeling approach was undertaken, i.e., the Slam-to-BIM approach, assuming as a starting point just the results of the point cloud representing the interior spaces. In this first case, a direct modeling from the point cloud has been carried out, a digitization process which prioritize the uses of 'masses' to pursue the accuracy of the model. This approach can be defined prevalently as heritage type, hence the emphasis on the 'H' (Fig. 72).

This approach seeks to approximate as closely as possible the geometry of the point cloud. As previously described, the USIBD prescribes five levels of accuracy for building documentation (LOA) generally ranging from 0 to 50 mm, although for LOA 10 the lower limit can be user defined. For this project, a LOA 20 was assumed, which tolerates geometric deviations of the order of a few tens of millimeters for the HBIM model with respect to the point cloud (Table 7).

Level	Upper Range	Lower Range
LOA 10	User defined	5 cm
LOA 20	**5 cm**	**15 mm**
LOA 30	15 mm	5 mm
LOA 40	5 mm	1 mm
LOA 50	1 mm	0

Table 7. Levels of accuracy for building documentation. USIBD.

Various Autodesk software were used for the process. To import the SLAM point cloud into Autodesk Revit (v. 2019 educational) it was necessary to use Autodesk Recap Pro as intermediary software. The point cloud was imported into Recap, where a cleaning phase was performed. Inaccurate points, largely due to the noise in the point cloud, strongly related to the peculiarities of the GeoSLAM ZEB1 survey, were removed, along with all objects that were not interesting for the definition of the building geometry, such as equipment or people.

Then, the point cloud in RCP format was inserted in the Revit environment and, starting from the definition of the corresponding levels, the HBIM modeling started. It is important to notice that, given the compatibility between these software, it is possible to keep modifying the point cloud in the Recap environment and that it will be automatically updated, once it has been imported, into a Revit project.

Within a BIM workflow, having a family library makes the modeling phase much faster. Parametric elements can be adapted to the needs of the project, increasing productivity. However, these elements, by default, are principally designed for new buildings and, consequently, often unsuitable for modeling historical architecture. Precisely, with the components currently available in the software it is not possible to accurately reproduce building irregularities. Therefore, regarding the modeling strategy adopted in this first approach, it was either necessary to transform some standard elements, such as columns, windows, or doors to make them fit or, in other cases, to use in situ component modeling strategies, i.e., 'in place masses' (using the Autodesk Revit definition) realized through traditional modeling functions such as extrusion, fusion, trajectory fusion, revolution, among others. Currently, the most common modeling technique used to create complex 3D objects, based on reality, is the direct approach. This working method is based on the extraction of features from the point cloud and the extrusion of these profiles along trajectories.

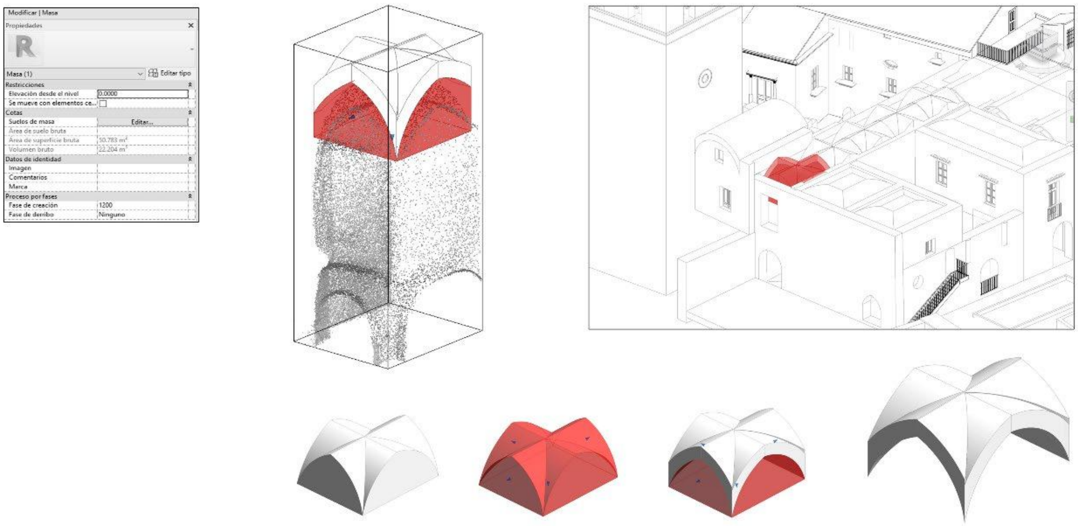


Fig. 73. HBIM mass modeling of vaults of Villa Rufolo.

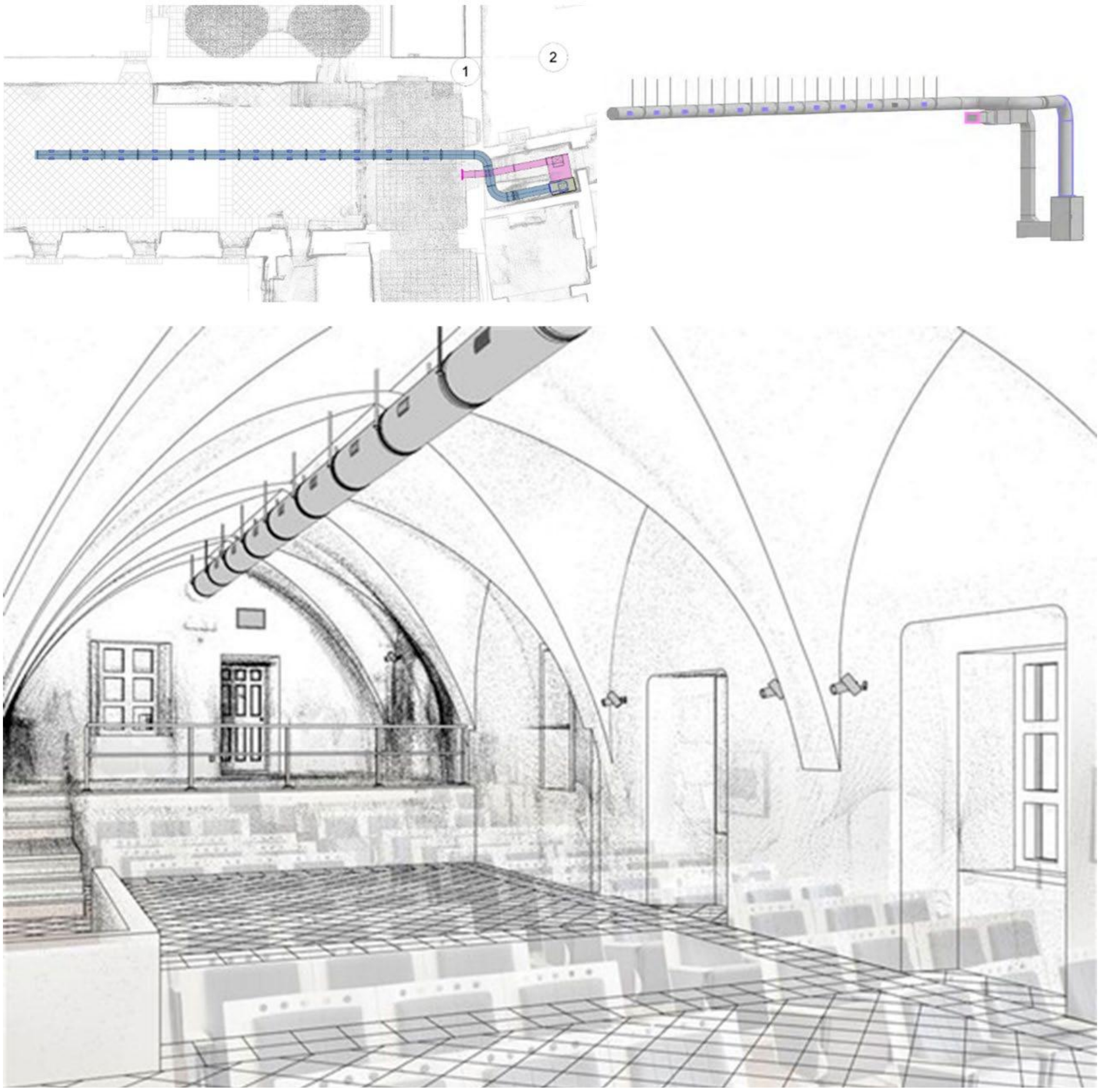


Fig. 74. MEP implementation in Villa Rufolo auditorium. Cotella V., 2020.

In historic buildings, it is common to have walls with inhomogeneous thicknesses, deviations, lack of perpendicularity or inclined walls. For example, to closely reproduce the concrete structures (specifically those ones realized in the 18th to rise the second level) of the *Chiostro Moresco* of Villa Rufolo, the 'mass' modeling technique was employed. This made it possible to generate an extrusion pattern to determine the inclination of the pillars.[1]

Due to their strong irregularity, the vaults of the *Chiostro* have been modeled as individual models defined 'in place', which, once again, provides a closer result to the real object. To model them, it was necessary to create opposing profiles in the form of a pointed arch and generate an extrusion between them. Then, to define the thickness of the vault, a new empty extrusion was created in both directions and placed in the project following the pattern established by the point cloud (Fig. 73).

In this first approach, in order to reduce the discrepancies between the point cloud and the model, and to respect the target level of accuracy, it was necessary to resort frequently to the use of irregular masses which, unlike the 'walls' family of systems, allows the geometry to be easily adapted to more complex situations. Although in this way, it was necessary to model almost every geometry individually, thus decreasing the efficiency of the whole modeling process, in terms of time and effort applied in its construction.

With this approach a faithful modeling of the surveyed object was achieved, verifying, with the 'as-built for Revit' plugin, the eventual deviations between point cloud and model. In general, the predominance of green surfaces evidences an overall accuracy, with the values of displacements varying within the range of ± 20 mm. While the surfaces colored in blue or red point out a deviation of ± 50 mm.

In the case of geometrically complex objects, typical of historical architectural projects as for the case study, a highly detailed model can be obtained, but often at the expenses of the size of the file produced and its general performance, as well as of the time required for its construction. Accurate and detailed representation of complex 3D geometry often results in very large files, which are more difficult to work with and increase the computational requirements.

As anticipated in preceding paragraphs, HBIM methodology furthermore allows the addition of non-geometrical information, that can concern, for example, the construction phase, the structure detailing, or the installations. In this first approach, the potentialities of BIM have been experimented enriching the model with useful information for the future management and maintenance of the Villa. Revit MEP (mechanical, electrical, and plumbing) was indeed tested too. Specifically, the Auditorium was also digitized with its electrical, air conditioning and ventilation installations. This information is advantageous for restoring, adapting, and reusing historic architecture (Fig. 74). However, this is a complicated task that requires a thorough investigation of conservation policies towards sustainable management, prevention, improved risk management, and effective maintenance and restoration techniques.

[1] The model, using this first approach, was built in 2019 before the incorporation of the 'slanted walls' in the 2021 version of Autodesk® Revit. The possibility to tilt the wall at given angle finally made it possible to create properly functioning walls, capable of hosting all the classic geometries, such as windows and doors, and easy to manipulate. https://www.autodesk.com/products/revit/new-features (March 2021).

Fig. 75. Scan-to-BIM of Villa Rufolo, the integrated point cloud as basis of modeling.

Fig. 76. Scan-to-BIM of Villa Rufolo, integrated point cloud and parametric model.

HBIM - Second modeling approach: SCAN to BIM

For this second approach, the integrated point cloud of the entire Villa Rufolo was used (Fig. 75). It can be defined as a 'more parametric' approach, perhaps less geometrically accurate, but closer to the principles of BIM. The criterion was to avoid elements created with 'masses' or components modeled 'in place', each element of the model has specific characteristics that will allow its reproducibility and was created based on a series of pre-programmed rules or algorithms, known as parameters. In other words, the model, or its elements, are generated automatically by means of internal logical arguments instead of being manipulated manually. Smart and, above all, flexible modeling has been prioritized, resulting in an instrument that allows us to concentrate on the interpretation of the characteristics hidden in each of the elements. The result is a smart object suitable to perform the most varied interpretations of architecture, from different points of view and with different purposes (Fig. 76).

The integrated survey allowed us to update the documentation of the case study and to provide a rigorous and metrically accurate digital reconstruction of the architectural artifact. Starting with a formal analysis of historical architecture, different geometries were distinguished, from the simplest ones, such as walls, beams, or columns, to the most complex ones, which could be hardly modeled through regular geometries, as in the case of vaults, domes, or decorative elements. In the academic field, they are currently working on the automatic conversion of points into geometry, via meshes and/or NURBS (Matrone et al., 2020). Although there are several plugins that come close to automatic conversion, such as Faro 'as built for Revit' or Point Cab 'Point4Revit', to mention a few, they are not yet suitable for complex architectures. Therefore, the modeling was performed entirely with a direct approach based on the integrated point cloud.

The geometric and stratigraphic complexity determined and characterized the subsequent HBIM parametric modeling according to the Scan-to-BIM process. Since the strengths of BIM are based, among other things, on standardization, it was chosen to optimize the process by reiteration, i.e., by experimenting with a simplified parametric approach, foreseeing a future reproducibility of the constituent elements.

Various Autodesk software were once again used. To import the integrated and georeferenced point cloud into Autodesk Revit (v. 2021 educational) it was necessary to use Autodesk Recap Pro as intermediary software. The decimated point cloud was imported into Recap, where scattered points were removed and regions were generated, in order to segment the point cloud into homogeneous zones. One of the most important steps in the process is precisely the segmentation, to ease the modeling phase by isolating, on a case-by-case basis, the areas of interest while also preserving the manageability of the ensemble. Once the cloud was inserted and fixed in Revit, maintaining the original orientation, the proper BIM modeling began. From a visual inspection and an efficient use of the regions, the layers of primary and secondary references were identified. An important step for the organization of the project was the creation of the main levels on all floors - theater level, entrance level, museum level and office level - and secondary levels corresponding to some roofs and other significant elements. An approach from the 'general to detailed' was used, using existing or ad-hoc created families. For essential elements, such as walls, systems families, which stratigraphy could be defined according to the specifics of the case study, were used. This is the case of stone, concrete, or ceramic-brick walls, which thickness varies from 0.10 m, in the case of some internal divisions, to 1.20 m, in the case of the medieval walls.

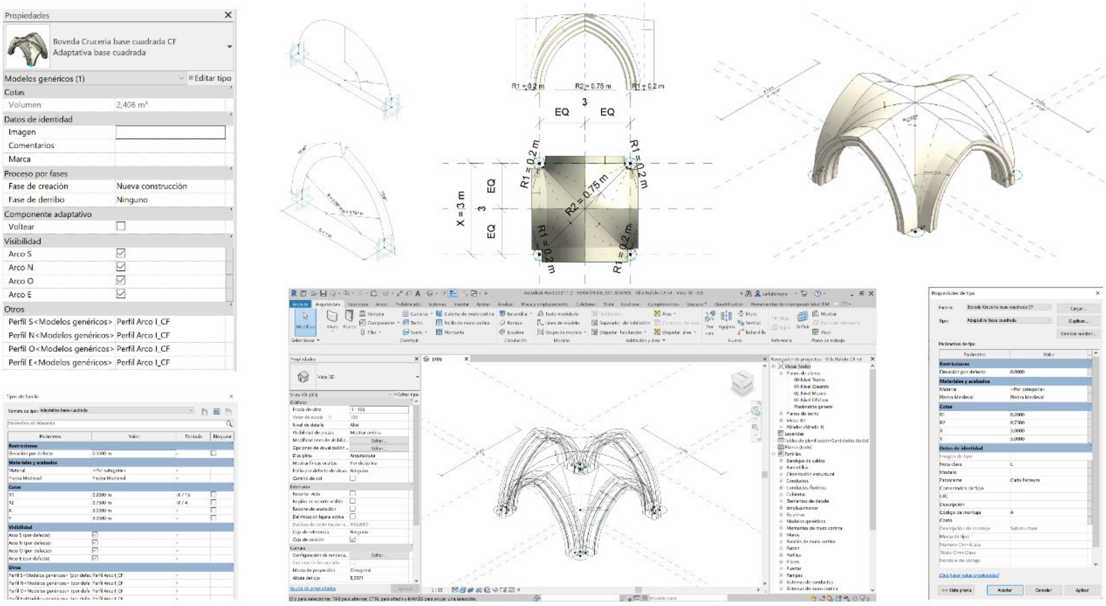


Fig. 77. HBIM adaptive vaults of Villa Rufolo.

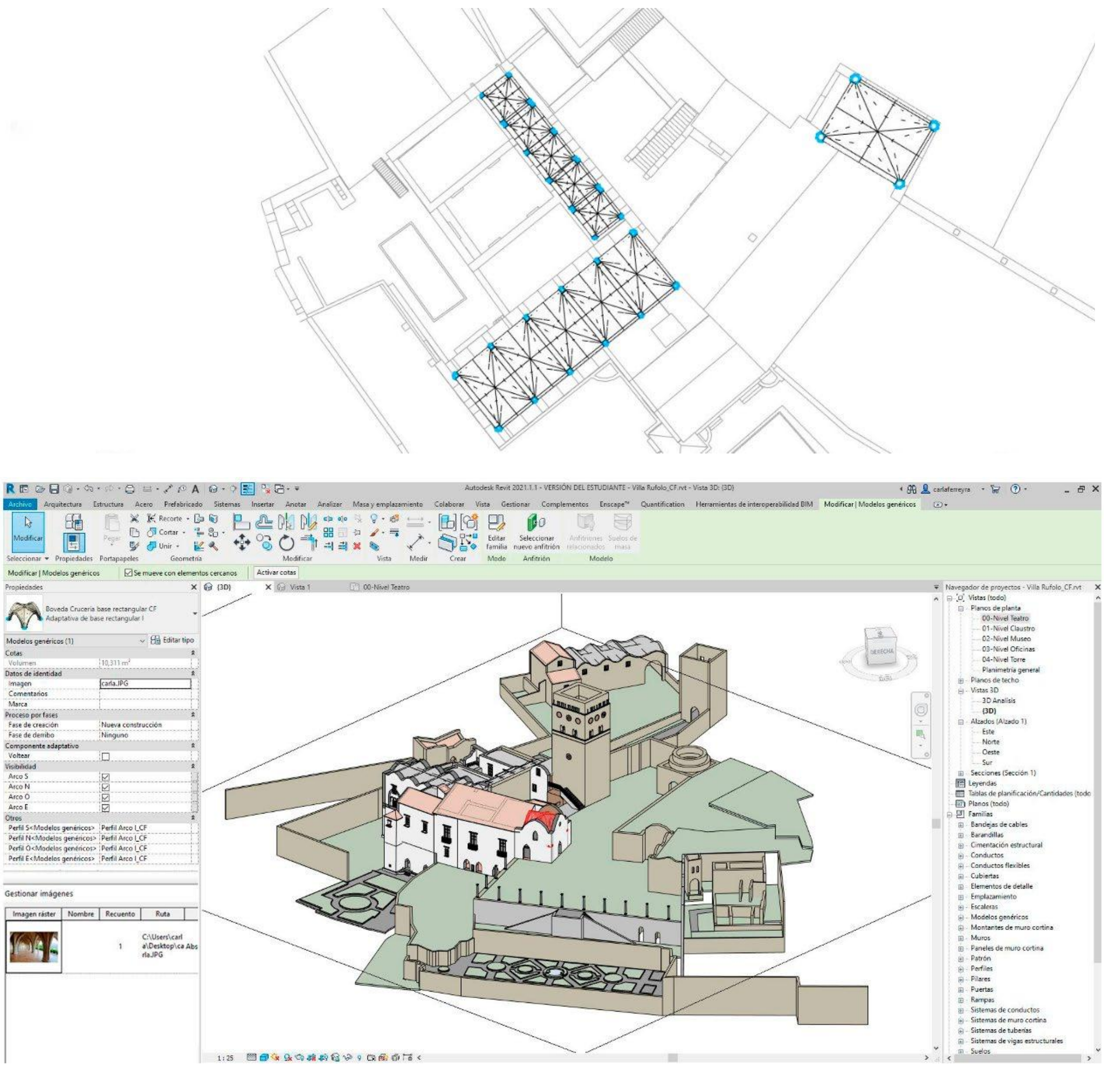


Fig. 78. HBIM parametric model of Villa Rufolo with information incorporated.

Other elements, such as windows or doors, were simply incorporated from the RFA library and adapted to the model fitting into the required dimensions. A few cases required though the uploadable families to be duplicated, to further modify them in the family editor and ultimately improve the adaptability of the geometry to the case study.

A 3D BIM model consists of individual building elements represented by 'intelligent' objects, i.e., objects with graphical attributes, data, and parametric rules. In other words, each object is characterized by a set of information describing its properties and its behavior in relation to other objects. The use of smart objects ensures the overall consistency of the model since the information is not redundant and is simultaneously updated in all views of the model. The parametric approach is used to model similar objects avoiding the time-consuming work of separately crafting elements with identical construction systems and similar shapes to fit different dimensions.

The methodology for the creation of parametric components in Revit can be defined according to the following workflow: studying the object, planning the families, creating the sub-elements, setting the reference planes, configurating the dimensions and parameters, and finally assembling the complex geometry in relation to the defined parameters, combining various modeling strategies: such as the profile definition and delineation, or the creation of the sweep along a trajectory, among others. Some adaptive and parametric families based on elementary geometries, that were created for the Villa Rufolo HBIM project, were built following the instructions of the Autodesk University video courses. With the available software tools, it is also possible to create pretty complex three-dimensional shapes, starting from adaptive families capable of being repeated and adapted into the model by using control points and accordingly to the project needs. In detail, the adaptive components can have one or several insertion points and their geometry will be consequently adapted according to the selected coordinates.

In particular, the domes were modeled as solid parametric families, with internal profiles extruded along a trajectory and were adapted, on a case-by-case basis, such as the *Torre d'ingresso* and the Arab bath of Villa Rufolo. The vaulted structures, on the other hand, were modeled as adaptive parametric families, once the plan schemes, the constituent parts and the proportions of the vaults had been defined, ultimately simplifying the geometry in arches and semi-arches (Fig. 77). These structures were mainly employed in the areas of the *Chiostro*, the Auditorium, and the Theater (Fig. 78). The pointed-and-semicircular-arched opening in the walls were created as parametric voids, with variable dimensions, i.e., height and width. In order for the imported family to be correctly hosted by the specific walls, even with different thicknesses, the 'cuts geometry' parameter was set. The complementary and decorative elements were created within the family editor environment in later phases, starting from DXF files; said CAD drawings represent an accurate geometric base, as a result of the vectorization of specific orthoimages obtained from the photogrammetric survey, or even from the same integrated point cloud (Fig. 79).

One of the great advantages of using BIM is the reduction of repetitive work, either by automating documentation and modeling processes or by using libraries of parametric architectural elements that can be adapted, as necessary. For modeling productivity, having parametric families that can be quickly adapted to real cases would contribute positively to the whole process (Banfi, 2019). As mentioned, in historic buildings, it is common to have walls with inhomogeneous thicknesses, deviations, and lack of perpendicularity, known to be difficult to reproduce in a HBIM workflow.

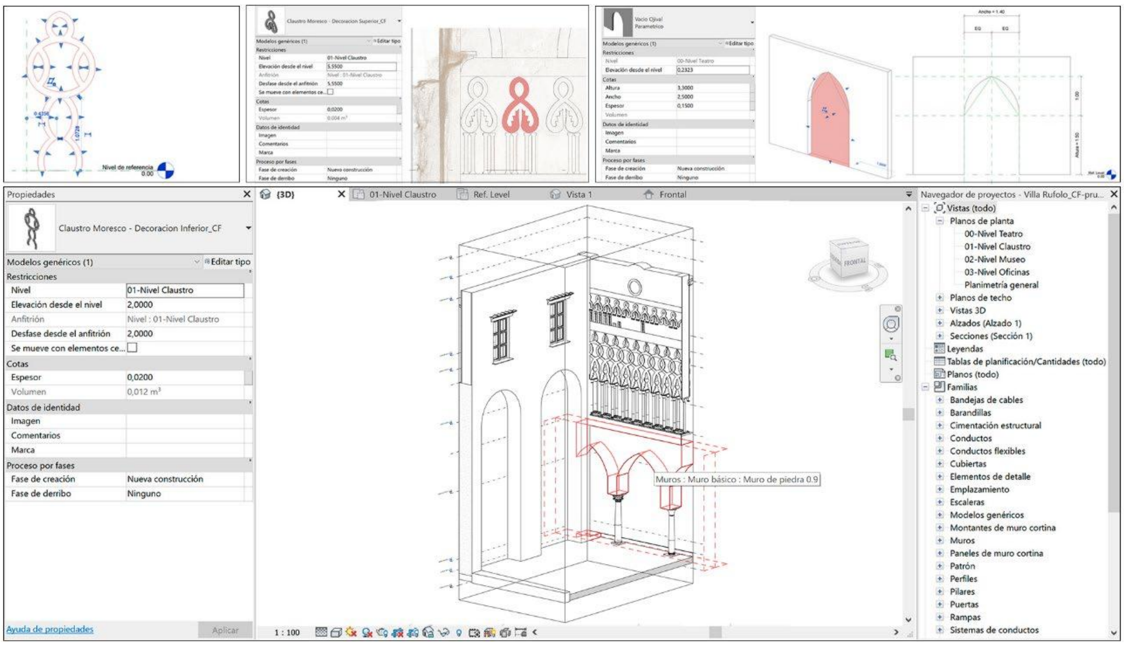


Fig. 79. HBIM parametric modeling of the Chiostro Moresco of Villa Rufolo.

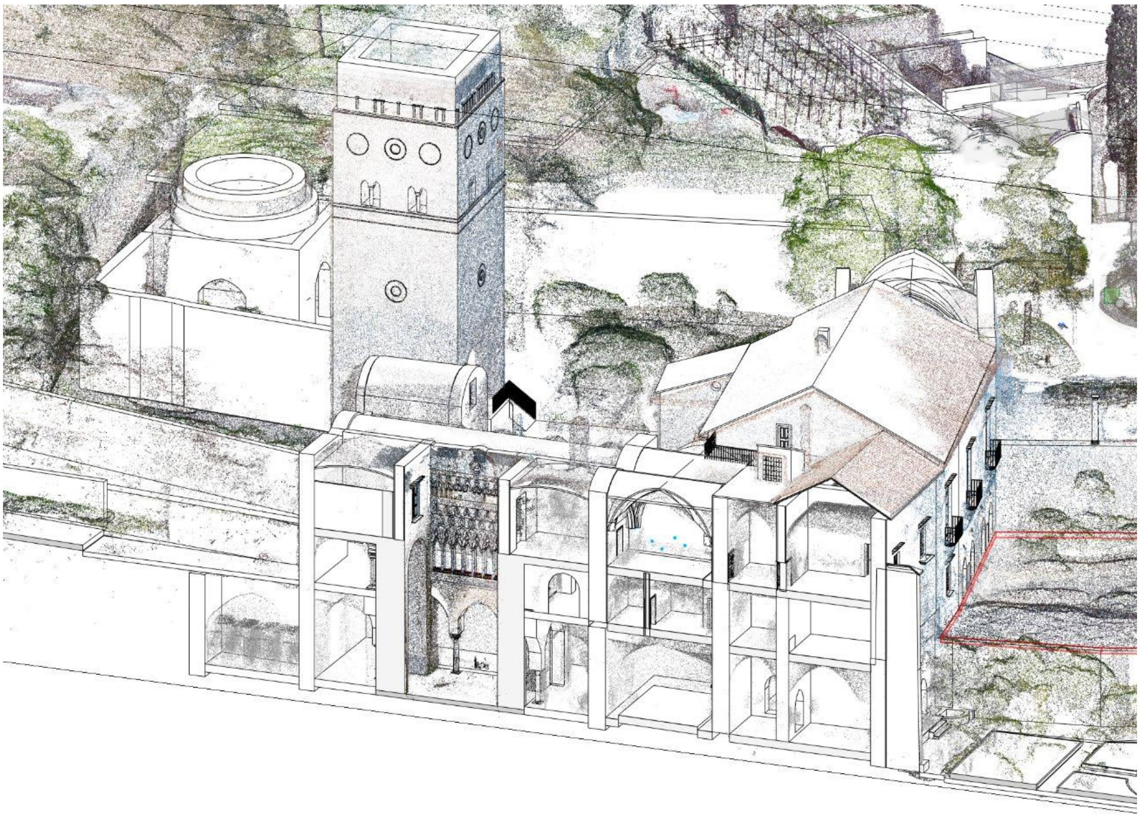


Fig. 80. Section of HBIM model of Villa Rufolo with integrated point cloud.

BIM software developer are working in this direction: the 2021 version of Revit just introduced the so-called ‘slanted walls’ with an angular parameter to define the slope. Moreover, the recently published Autodesk roadmap introduces, for next releases of the software, ‘tapered walls’, characterized by a variable thickness and the possibility of have just one tilted side. Previously, this kind of geometries were to be modelled as in place masses, making it difficult for them to host other classical components, such as windows. For said reasons, this is, by far, a turning point in HBIM modelling optimization.

The parametric approach applied in this case study highlighted some of the already-known problems of a HBIM workflow, such as the lack of specific libraries of parametric objects for historic buildings, the existence of some limitations in the modeling and parameterization of certain building elements, the absence of an exhaustive classification, among others.

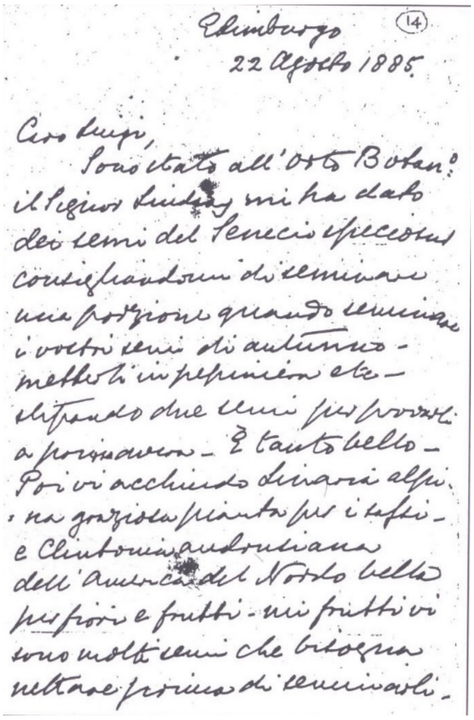
In any case, for the purposes of programmed heritage conservation, an exact geometric reconstruction is often not necessary, although it is important for each element to be recognizable and spatially referenced within the whole. The creation of a model is, and must be, an abstraction and a simplification of reality and, as such, implies discrepancies between the representation and the real object (Fig. 80).

For modeling efficiency, it is important to define in advance the levels of development, both informative and geometric, according to the specific objectives and needs. In this way, the model becomes a ‘repository’ of digital data, to be managed within a CDE (Common Data Environment, defined as ACDat by the Italian regulation), i.e., a digital workspace. The result of this approach was an HBIM model in which the architectural elements are simplified, but capable of ensuring the accuracy of values related to space management and component preservation. This choice, although, disadvantageous in terms of accuracy, since parametric modeling is much less flexible in the representation of complex and irregular geometric shapes, allows to configure the behavior of the components and to establish constraints and topological relationships useful in the management of the 3D model (Bruno & Roncella, 2019).

The main objective of this application was to generate not a mere geometrically correct model, but one to populated with other kind of information. The thesis explores indeed the use of HBIM as a tool to incorporate quantitative and qualitative data into the model. Such as archival documentation, technical drawings, point clouds, orthoimages, current and historical photographs, particular features, technical reports, material analysis etc.

For future developments, it is planned to incorporate even unpublished data into the model, such as Francis Nevile Reid’s charts or the authentic scan of Luigi Cicalese’s early '900 photos. It is well known that old photographs play a unique role in the documentation process, as they report a truthful and invaluable visual representation of the past. As opposite to other media, such as drawings or sketches, that are obviously subjective.

The result of the experience is a multi-dimensional database where the construction of the three-dimensional image synthesizes the critical interpretation of reality, thus becoming a useful support for the management and conservation to further update the current state of knowledge of our monument. Thanks to the use of the BIM methodology and highly-geometric-precise models, it was possible to begin to structure the architectural information of the historical heritage, from its origin to the present day. The substantial improvement is the possibility of storing in the same model, that becomes a repository, all the successive phases and interventions to be carried out on the building itself (Fig. 81).



Edimburgo (14)
22 Agosto 1885.

Caro Luigi,
Sono stato all'Orto Botan.co
il Signor Lindsay mi ha dato
dei semi del Senecio speciosus
consigliandomi di seminare
una porzione quando seminare
i vostri semi di autunno -
mettendoli in pepiniera etc -
serbando due semi per provarli
a primavera - È tanto bello -
Poi vi acchiudo Linaria alpi-
na graziosa pianta per i sassi -
e Clintonia andrewsiana
dell'America del Nord bella
per fiori e frutti - nei frutti vi
sono molti semi che bisogna
nettare prima di seminarli -

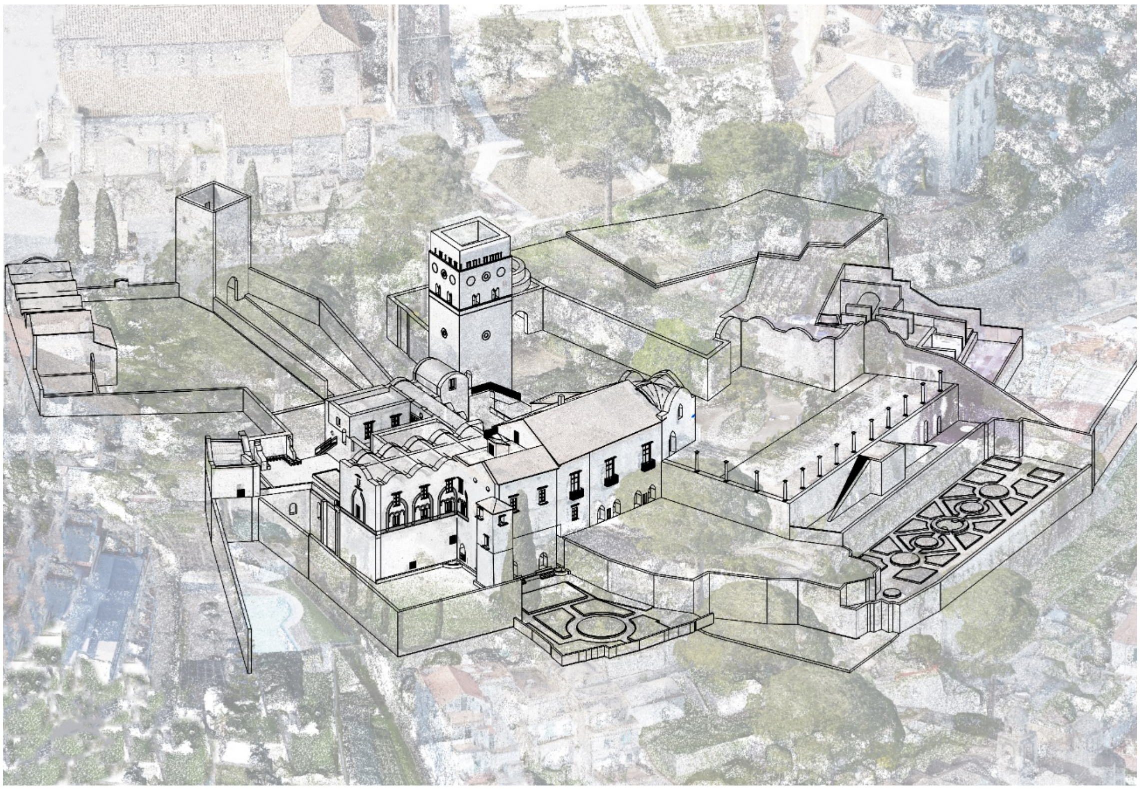


Fig. 81. Multi-dimensional database of Villa Rufolo (below) with Reid's charts (above) incorporated.

IMAGE-BASED TECHNIQUES AND HBIM INTEGRATION

The survey techniques we have discussed throughout this thesis, such as TLS, MLS, photogrammetry, along with other techniques currently under development, are widely used for architectural surveying and are combined to obtain high resolution documentation with geometric accuracy and chromatic fidelity. Although the results are extremely accurate, point clouds and meshes are not semantically structured per se, as they do not possess information related to materials, physical properties, etc. Villa Rufolo was considered a good opportunity to experiment a HBIM methodological procedure in historical architecture in terms not only of information gathering, but also as a tool for interpretation, knowledge, and dissemination. Seeking to integrate, in the same database, remote sensing techniques with HBIM modeling, the photogrammetric texture has been incorporated into the model, increasing its level of development. This has been done in an iconic sector of Villa Rufolo, the *Chiostro Moresco*. Through this integration, a graphic documentation has been favored, allowing an accurate visual simulation of the materials, useful for technical applications such as material classification, or degradation analysis, but without losing in any case the information of the BIM model.

Seeking to preserve the access to intelligent objects, at the same time, disseminate the Cultural Heritage with real-time visualization strategies, the *Chiostro* has been selected to test the possibility of increasing the level of model development by incorporating the photogrammetric texture and improving the final graphic rendering. In an attempt to combine parametric modeling and photorealistic visualization within BIM, we decided to implement the photogrammetric texture as layered information, taking advantage of emerging technologies such as 'Virtual Reality' and 'real-time rendering' plugins, which operate in the same workspace. In this way, the photogrammetric texture assumes a semantic role, providing information about the actual conditions of the facades, while serving as a reliable source to improve the level of geometric detail (LOG) of the model. The goal of the experimentation is, in effect, to produce a geometric and graphical model ready for the as-built level. Emerging VR technologies operating in the native BIM environment offer the undeniable advantage of extracting and visualizing information useful for specialists in the AEC industries and for the documentation of Cultural Heritage, allowing to interact with the building without even being on site, in order to schedule maintenance operations (Osello et al., 2018).

The LOD of the model was increased by incorporating photogrammetric texturing and contributed to improve the final graphic rendering to extend the reading of the architecture to a wider audience. The orthoimages were exported in a TIFF format, with the annexed TFW, to be already sized when imported in a CAD space. They were then overlapped above the external elevations of the *Chiostro*, previously exported as DWG from the Revit model, to measure the dimensions used to refine the *color maps*, according to the modelled walls geometry; these reshaped maps were later used to implement the *photogrammetric materials* into the Revit environment. To create them, the orthoimages were indeed to be cut and graphically processed, adding a simple grey shade to cover the empty un-surveyed areas. *PBR Materials*[1] were considered for this application, given their advanced graphic rendering properties, to maximize the visualization effect. For the case, *color, roughness, relief* and occasionally *cutout* and *ambient occlusion maps* were selected. The cut photogrammetric orthoimages were directly used for the *color map*, also called as *albedo*.

[1] *Physically Based Rendering* (PBR), or *Physically Based Shading* (PBS), is a method of shading and rendering that provides a more accurate representation of how light interacts with surfaces, to represent assets from a physically accurate standpoint. https://help.sketchfab.com/hc/en-us/articles/204429595-Materials-PBR (last accessed March 2021).

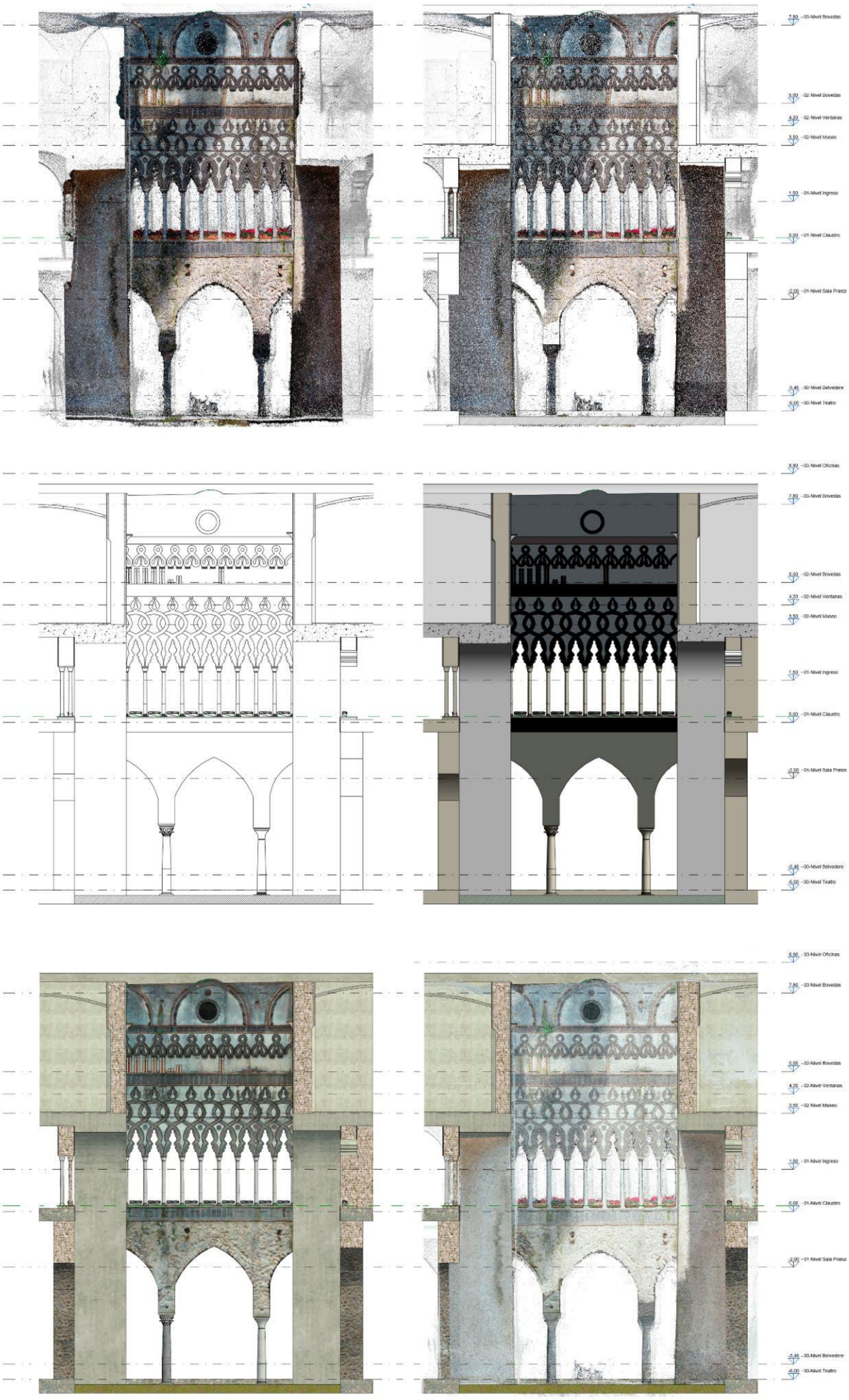


Fig. 82. Point cloud, Scan-to-HBIM process, image-based integration.

The *bump map*, also known as the *relief map*, can either be a black-to-white *height map* or a RGB *normal map*. The greyscale *height map* borrows a well-known 3D GIS concept, used to assign an elevation to the Lidar surveys, therefore the darkest areas are set to correspond to almost null zeta displacement, as opposite to the lightest that will shape the overhangs. On the contrary, if the *bump map* is set as *normal map*, it means that the RGB values in a point will matched to XYZ displacement for the pixel projection. The *roughness map,* as the opposite of the *glossiness one* is again a greyscale image, where white assign the maximum roughness, intended as visual noise. The *Revit cutout map* is then used to make graphically disappear the areas identified in black, while the *ambient occlusion,* being a specific characteristic of the advanced PBR materials, is used to further improve the refraction effects, for them to be more representative of lighting actual physical behavior.

To obtain the *bump* and the *roughness maps* from the photogrammetric texture, the orthoimages were accurately analyzed. The wall patterns were investigated, in order to correctly assign the proper amount of gray to match the conditions of different areas, so to ultimately reproduce their real-world plasticity. The results produced at the ending of the modeling and texturing process is not strictly definable, according to regulations, as an *as-built* model, lacking the required information concerning the constructive and managing stages. However, it is renowned that the LOD scale is not one-hundred-percent appropriate to evaluate HBIM models; it shows indeed a few deficiencies in describing some fundamental aspects of the Cultural Heritage, while some of the requirements, e.g., installation information, seem incompatible with an existing and historic artifact.

The developed model is then to be accounted as a LOD 350 according to the AIA classification, corresponding to the LOD D - *Detailed Object* in the Italian regulation; it is indeed modelled as a specific system, in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Particularly this last aspect was guaranteed for the whole Villa, in which the modelling phase was prepared by accurately investigating the constructive system, so to optimize the subsequent steps. The orthoimages combined with the PBR maps are capable of both graphically simulate the materiality of the modeled object, while also providing a detailed and metrically accurate representation of the conservation state of the surfaces, with the additional possibility offered by Enscape software to select the BIM elements and have immediate access to the related properties within the same rendering window, thereby offering to most stakeholders an immersive and smart experience into digital heritage

The work reveals a possible step forward in the field of digitization. The potential of the proposed methodology, which could be summarized as Scan-to-HBIM-to-Real Time Rendering, has been tested to meet preservation and restoration needs, connecting an entire 3D database to the object containing informative attributes. The HBIM model is not static, the LOD can be increased at any time, resulting in a model that can be modified quickly and efficiently to increase productivity. In addition, the results are already optimized for real-time rendering applications operating within BIM software, so any changes applied to geometry and/or materials will be immediately visible, while equally direct and fast access to object properties is also visible in the rendering window.

Adding materials derived from photogrammetry in the BIM environment allows, therefore, to directly measure and evaluate the pathologies from which our architectural artifacts may be affected. As-built documentation is once again a fundamental tool for management and maintenance work, as well as for updating the state of knowledge about the *Chiostro Moresco* of Villa Rufolo (Fig. 82).

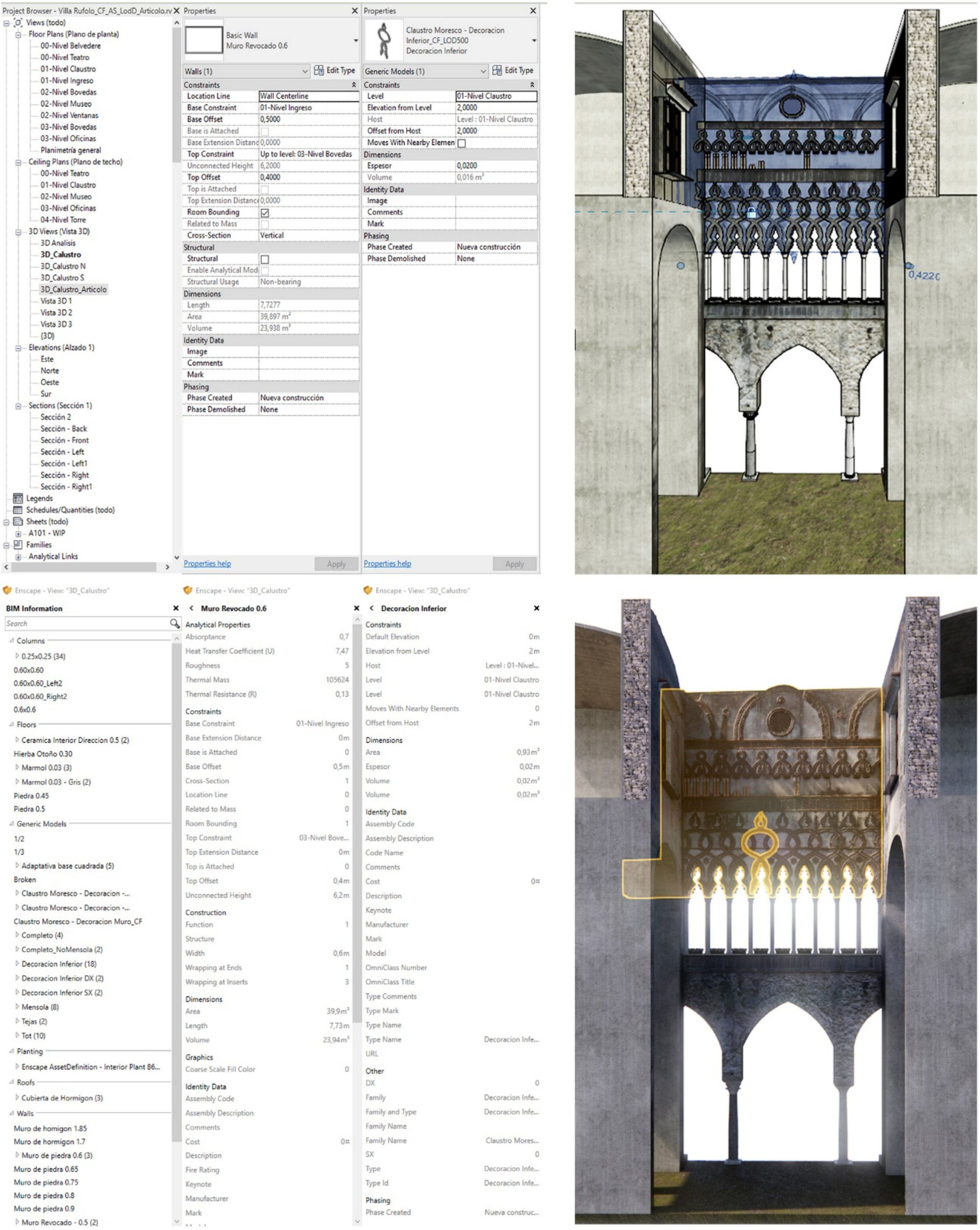


Fig. 83. BIM objects selections in the Revit (above) and Enscape (below) workspace.

The application of photogrammetric texturing to the BIM model not only allows for a timely realistic visualization of the object, but also maintains the previously incorporated technical information. These innovative visualization models not only offer a scientific basis, but also represent an important tool for the dissemination and fruition of a real heritage in digital form (Fig. 83).

The potential of this methodology has been demonstrated in the critical reading of historical elements and in the response to emerging restoration and conservation demands, based on the possibility of having a complete 3D data base of the entire object with information and attributes incorporated, which can be extracted in different data formats to be analyzed in subsequent processes and by different professional figures.

These results promote the dissemination of Cultural Heritage, which can only be achieved by increasing users' knowledge of the property. Therefore, a texturing as accurate as possible was considered essential to achieve an attractive photorealistic visualization. Experimentation made it possible to achieve a level of graphic and geometric modeling suitable for an as-built model of Villa Rufolo, in order to realistically simulate its materiality (Fig. 84).

The correspondence of the model to the survey data can vary depending on the technique used to carry it out; the mesh model is the most faithful to the survey data, while the parametric model always considers a certain degree of abstraction and data simplification. Three-dimensional CAD models are a useful addition to heritage projects, as they allow visualization for conservation interventions, but the parametric elements and the possibility to store almost endless information make the BIM models stand out. Moreover, BIM models are way lighter than point clouds and generally much easier to handle. The BIM models come then as a natural consequence of surveyed models and become indispensable to document the characteristics of the case study, eventually to further analyze the object. Other possible applications are video games for educational purposes or immersive models to promote tourism.

Fig. 84. Image based techniques for the incrementation of HBIM Level of Development.

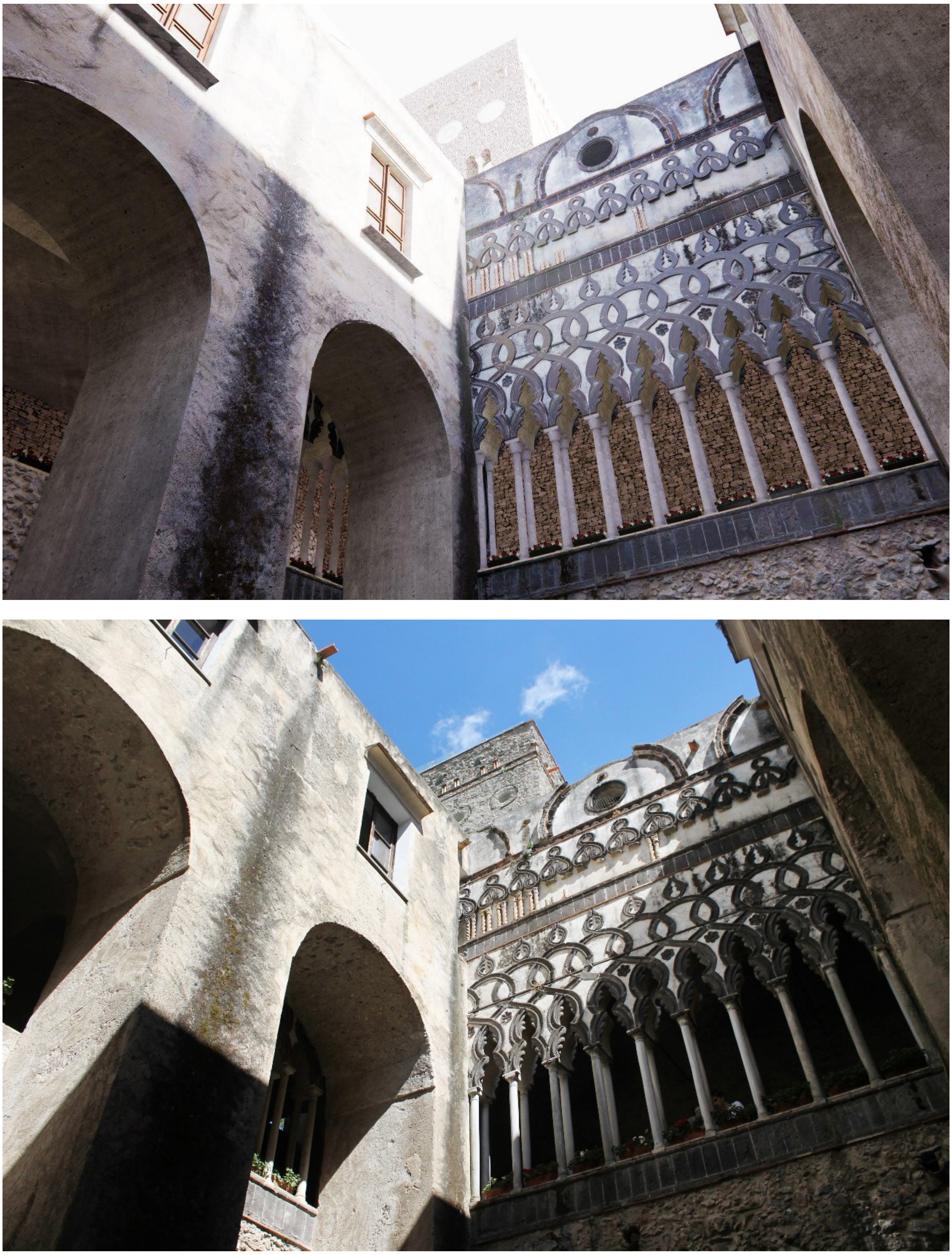


Fig. 85. Chiostro Moresco of Villa Rufolo comparison between 3D model (above) and photograph (below).

6.1.3. Considerations

Historical BIM can be used as a heritage management tool, as a database and information source, to support future research and studies. Possible applications of BIM in the heritage sector vary according to the scope and purpose of a project, and include the establishment of an information repository for: documentation and recording activities, condition monitoring, conservation planning, preventive maintenance, heritage management, heritage interpretation, tourism flow management, evaluation of intervention options, work scheduling (conservation, repair, maintenance and reuse), construction simulation, project management, security, fire safety, visitor safety and health and safety planning, disaster preparedness. Compared to BIM, that is mainly focused on collaborative work, classification, and standardization, HBIM places more emphasis on the data behind the heritage building and the techniques for modeling its structures accordingly to the constructive point of view.

The advantage of BIM technology lies in the possibility of digitally managing all the information of a building and, for the present work, this potential was exploited in different ways: firstly it represents a powerful tool for geometric data management, using data from an integrated 3D survey to accurately model the Villa; secondly it is rich in information content, offering the possibility to associate the elements with semantic content related to materials, degradation and conservation interventions. Ultimately the HBIM technology is ideal for: storage, digitization and systematization of historical data, interoperability between disciplines when carrying out interventions, management of costs, time, resources, etc.

In the current state of technological development, it is necessary to define a fair compromise between model accuracy, file size, modeling time and limits of software capabilities. The available solutions are many and change according to each case study and model objectives. The main needs are usually: to easily manage and visualize a database of structured information, to share models and their content between experts with different knowledge, to manage conservation activities and to improve the level of knowledge of a given case study.

In a Cultural Heritage context, it unfortunately still feels as though the time and cost of full 3D parametric modeling might not be justifiable. Even though HBIM models can be used not only for conservation and planned documentation, but also for structural or energetic analysis, plant design, rehabilitation, or restoration projects. Hereby, it is proposed to implement in the documentation of Villa Rufolo the 7 dimensions of BIM: geometry (3D), historical phases (4D), structural elements and materials takeoffs (5D), model analysis for sustainability purposes (6D), conservation and restoration management (7D). In any case, it is fundamental to mention that the complex nature of heritage buildings, as cultural and community resources, still raises a lot of questions about what data is useful to meet the needs of a wide range of professional figures involved in heritage management.

Historical BIM is, by definition, a multidisciplinary process that requires the contribution and collaboration of professionals with very different skills. The model presented does not represent a final result of the reconstruction, but aims at assisting in the process of interpretation, hypothesis, and verification of the reconstruction. These are comprehension activities that serve to document the level of knowledge of an object of study and provide information on the guidance and standards available to effectively manage the entire life cycle of a building (Fig. 85).

Architecture is the unbribable witness of history, because we cannot speak of a large building without recognizing in it the witness of an era, their culture, their society, their intentions. Octavio Paz.

6.2. A case study of Cultural Landscapes in Germany

6.2.1. Introduction to Mainstockheim and Oberschwappach Ebracher Hof

Digital Technologies has become a powerful tool for the representation and interpretation of Cultural Heritage, landscape, and architecture. During the traineeship in the laboratory of Digital Technologies on Heritage Conservation (DTHC) of the University of Bamberg the opportunity has been taken to deepen the MLS technique (not sufficiently explored in the previous case study). The Cistercian landscapes, in particular the *Ebracher Hof in Mainstockheim* and the *Ebracher Hof in Oberschwappach* (Fig. 86) have represented an interesting scenario on which to implement the CAME methodology, test the latest updates of the SLAM techniques characterized by the rapid acquisition of data, and to ascertain the best practices of a new instrument, generating an accurate infographic to be explored in the project "*Cisterscapes - Cistercian Landscapes Connecting Europe"*[1].

Fig. 86. Administrative seats with gardens belonging to Ebrach Abbey. Google Earth.

6.2.2. CAME Methodology application

The CAME methodology has been implemented to two Cistercian Landscapes in Germany, for building knowledge, creating meaning, and making culture accessible to everyone (Fig. 87).

Fig. 87. CAME - workflow implemented in Cistercian Landscapes.

[1] Cisterscapes Project - http://cisterscapes.eu/ (last accessed March 2021).

EBRACHER HOF IN MAINSTOCKHEIM (49°46'38.3"N 10°09'01.4"E WGS84)

The *Ebracher Hof in Mainstockheim* (Fig. 88), a community in the Lower Franconian district of Kitzingen, was built at the beginning of the 17th century. In 1500 the monastery of Ebrach established a monastic office in *Mainstockheim*. The Abbot of Ebrach, Johannes V. Dressel had built the court between 1618 and 1630. Under Abbot Wilhelm Sölner of Ebrach an impressive garden was created from 1727 to 1734. The court is classified as a historical monument by the Bavarian State Office for the Preservation of Historical Monuments[1], while the underground remains of previous buildings are listed as ground monuments. The rectangular complex with corner towers has richly articulated Renaissance gables and an elaborate portal. In the chapel, the painted stucco decoration of the construction period has been preserved. In 1961 the Brandner family acquired the *Ebracher Hof*. After extensive renovations, the Schloss *Ebracher Hof* retirement home was opened[2] (Hans Bauer, 2012).

The architectural elements of the historic garden serve as identifying features that describe the progression of uses of the site by its subsequent owners. Therefore, these elements are key markers that document the history of the site within this cultural landscape. The importance of their conservation is therefore relevant to ensure the integrity and authenticity of the property.

Fig. 88. Ebracher Hof in Mainstockheim. Combination between raster image and point cloud.

[1] https://www.blfd.bayern.de/ (last accessed March 2021).
[2] https://seniorenheim-ebracher-hof.de/ (last accessed March 2021).

EBRACHER HOF IN OBERSCHWAPPACH (49°58'06.5"N 10°28'37.4"E WGS84)

The *Ebracher Hof in Oberschwappac*h (Fig. 89) is a baroque palace, a district at the northern end of the commune of Steigerwald in Knetzgau in the district of Haßberge in Bavaria. Under the abbot Wilhelm I Sölner, the palace was built in the center of town from 1733 to 1738 and clearly shows the architectural language of the Würzburg court architect Joseph Greissing, who apparently many years before the beginning of the construction, had probably submitted plans. The palace served to administer the properties of the Cistercian monastery of Ebrach in the surrounding area and was also used as the summer residence of the abbots of Ebrach[1]. After the abolition of the monastery of Ebrach in 1803 in the course of secularization, the last abbot of Ebrach, Eugen Montag, was exiled to the castle of *Oberschwappach*. He died there in 1811. As a result, the castle had different owners and was in poor structural condition when it was acquired by the community of Knetzgau in 1985. Today the castle houses a museum, a kindergarten, and a restaurant[2].

To contribute as being part of the route of Cistercian Cultural Landscapes. This case study serves as comparison to analyze the geometry and find similarities and prototypes of the typology of Cultural Landscape.

Fig. 89. Ebracher Hof in Oberschwappach. Combination between raster image and point cloud.

[1] https://www.knetzgau.de/index.php?id=16356 (last accessed March 2021).
[2] https://www.schlossrestaurant-zeitlos.com/ (last accessed March 2021).

SLAM-BASED TECHNIQUE

This case study will focus on deepening the SLAM technique. SLAM can trace its early development back to the robotics industry in the 1980s and 1990s. Robotics engineers had a problem – how to get their autonomous vehicles to move around the factory floor without bumping into walls, people, or indeed each other. Being indoors, they could not rely on GPS for navigation. The engineers realized that if they could design an algorithm (like a set of digital instructions) that could concurrently map and navigate through that space, they could solve the problem.[1]

SLAM technology is one of the solutions that use the data sequence acquired during motion for estimating the relative poses in real time (Fig. 90). The problem asks if it is possible for a mobile robot to be placed at an unknown location in an unknown environment and for the robot to incrementally build a consistent map of this environment while simultaneously determining its location within this map (Durrant-Whyte & Bailey, 2006).

SLAM uses sensors to collects visible data (such as camera imagery) and non-visible data (such as LiDAR) with basic positional data collected using inertial measurement unit (IMU). Together these sensors collect data and build a map of the surrounding environment. By moving its position within the environment, all environmental features will move in relation to the device and the SLAM algorithm can improve its estimate with the new positional information. SLAM is an iterative process - the more iterations the device takes, the more accurately it can position itself within that space. The higher the iteration process, the higher the positional accuracy. This cost more time for computation and high-configuration hardware with parallel processing capabilities of GPUs.

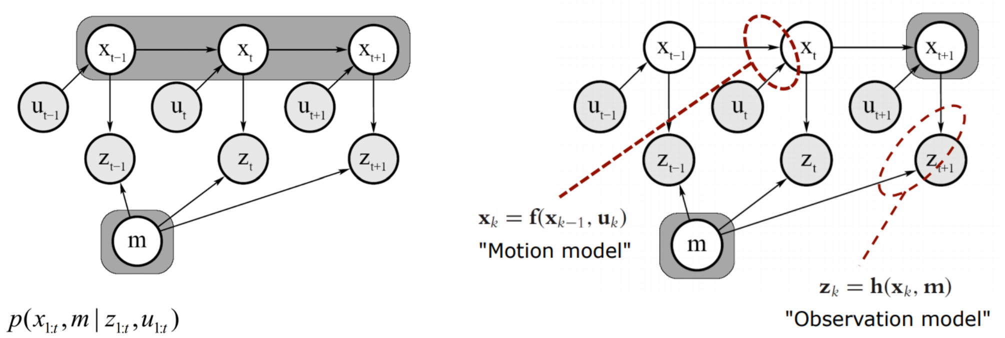


Fig. 90. Graphical model of SLAM technology.[2]

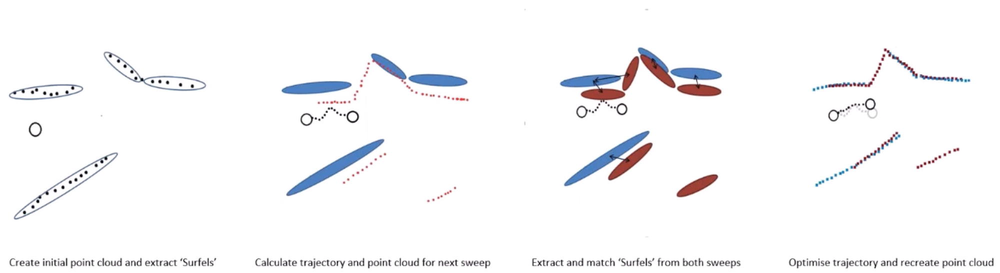


Fig. 91. Trajectory optimization of SLAM technology.[3]

[1] https://geoslam.com/blog/2019/01/18/what-is-slam/ (last accessed March 2021).
[2] http://ais.informatik.uni-freiburg.de/teaching/ss12/robotics/slides/12-slam.pdf (March 2021).
[3] Piniotis et al., 2020.

SLAM-based mobile laser scanners are a convenient inventory tools due to their mobility and velocity of acquisition. Not need to remain static while scanning: many research studies have demonstrated this simple and portable device to efficiently collect data during movement. In terms of the speed of data collection, previous study has proven that an MLS was several times faster than a TLS (Liang et al., 2014).

Briefly, from the first sweep of the point cloud, sections which are called *surfels* are extracted to represent the unique shapes within the point cloud. The trajectory is then calculated for the next sweep of data using the IMU and *surfels* are extracted again in the same way. The two sets of *surfels* are then used to match the point clouds together and subsequently correct and smooth the trajectory estimation. Following this iterative process, the final point cloud is recreated based on the new smoothed best estimate trajectory (Fig. 91). To further optimize the trajectory and limit any IMU drift, a closed loop is performed such that the start and finish environments are accurately matched together (Piniotis et al., 2020).

In comparison to TLS, MLS reduces the required time on-site. However, the data acquired by MLS is often less accurate than TLS point cloud data, due to the propagation of positioning errors within MLS point cloud data.[1]

SLAM-based MLS has the potential to improve mapping efficiency compared with conventional field measurements, as well as to compensate for the limitations of other laser scanning techniques, such as having to transport the scanner and associated equipment from site to site, which is one the major disadvantage of TLS in terms of timing.

For the case studies recording has been used a ZEB Horizon (GeoSLAM Ltd., Nottingham, UK), recently acquired by the chair of Digital Technologies in Heritage Conservation of the Institute for Archaeology, Heritage Sciences and Art History (IADK) of the University of Bamberg[2] (Figs. 92, 93).

The features of the specific SLAM Algorithm are:

Post-capture processing: which requires to begin processing your scan after completing the capture. It takes longer than real-time processing, but it also ensures greater reliability in your scan results. Depending on the timeline, the extra processing may not prove to be a big issue and it is possible to use some inactive periods to process the data, to ensure the highest quality data without any extra active time.

An IMU and a Lidar sensor: SLAM approach that is effective in open areas that contain distinct 3D geometry and features (architectural details and decorations). However, can have trouble in areas dominated by planar shapes, like walls.

Post-scan colorization: which requires a secondary camera (ZEB cam) attached to the device and requires the performing of extra processing steps in the workflow to achieve the desired results. Importing a MP4 to the software will colorize the point cloud data after the processing of the scan.

[1] Accuracy Comparison: TLS (± 5mm) > MLS (± 5cm).

[2] https://www.uni-bamberg.de/en/iadk/ (last accessed March 2021).

Fig. 92. The ZEB Horizon in Cistercian Landscapes, walking around the area. Photo by Mona Hess.

Fig. 93. The ZEB Horizon in Cistercian Landscapes, fixing a reference point. Photo by Mona Hess.

The ZEB Pano (Table 8) capture 360° panoramic photography for enhanced surveys using the ZEB Horizon.

Camera Model	RICOH THETA V 360 Degree
Resolution	14 MP
Weight	209 g

Table 8. GeoSLAM ZEB Pano specifications.

The ZEB Horizon (Table 9) system drastically outperforms the existing sensors (i.e., ZEB1[1], ZEB-GO[2], and ZEB-REVO-RT[3]) in terms of data acquisition rate (300,000 points/s vs. 43,200 points/s) and max. scanning range (100 m vs. 30 m).

Maximum range	100 m
Points per scan line	937 (0.38° interval)
FOV	360° x 270°
Scan points per second	300,000 points/s
Scan range noise	±30 mm
Laser safety classification	Class 1 Eye-safe per IEC 60825-1:2007 & 2014
Laser wavelength	903nm
Operating temperature	0°C to +50°C
Protection Class	IP54
Power supply	14.8VDC ~ 1.5A
Weight	Scanning head with handle 1.49 kg Data logger 0.72 kg Battery 0.55 kg Carry case and contents 4.2 kg
Dimensions	Scanning head 216x108x266 mm (15 3mm excl handle) Carry case and contents 470x220x180 mm
Battery life	Approx. 3 hours continuous use

Table 9. GeoSLAM ZEB Horizon specifications.

The ZEB Cam (for Horizon) is a color camera accessory for GeoSLAM's ZEB Horizon. ZEB Cam incorporates a Hawkeye Firefly 8S action video camera. The image data collected by the camera can be viewed alongside the 3D point cloud created by the ZEB Horizon and used to extract contextual information (Table 10).

Camera Type	Hawkeye Firefly 8S
Mode	Video
Video Resolution	4K
Frames per Second	30
Image Resolution	3820 x 2160
FOV	~170°x 90°
Logging Medium	Internal SD card
Power Supply	Powered by ZEB Horizon scan head
Image Syncing	Linked to scan head timing board

Table 10. GeoSLAM ZEB Cam specifications.

[1] The first laser scanner of GeoSLAM Ltd. was introduced in 2013 with a spring-mounted sensor head. It was the one used for the previous case study.
[2] https://geoslam.com/solutions/zeb-go/ (last accessed March 2021).
[3] https://geoslam.com/solutions/zeb-revo-rt/ (last accessed March 2021).

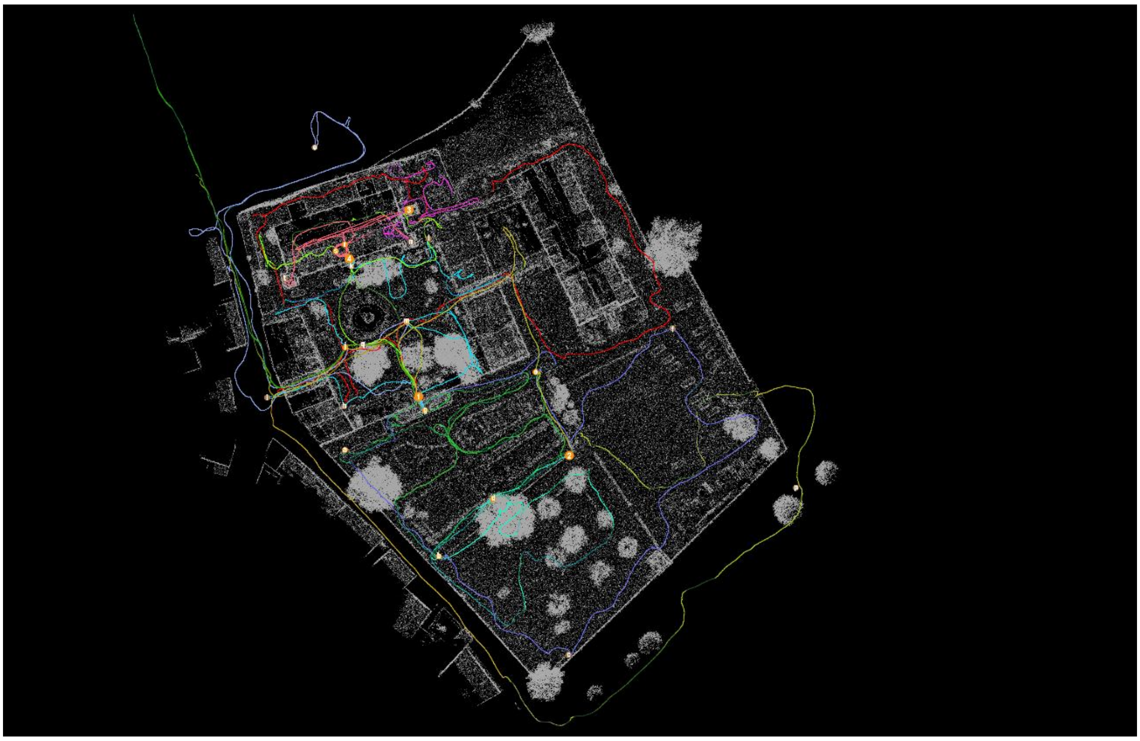


Fig. 94. Mainstockheim trajectories.

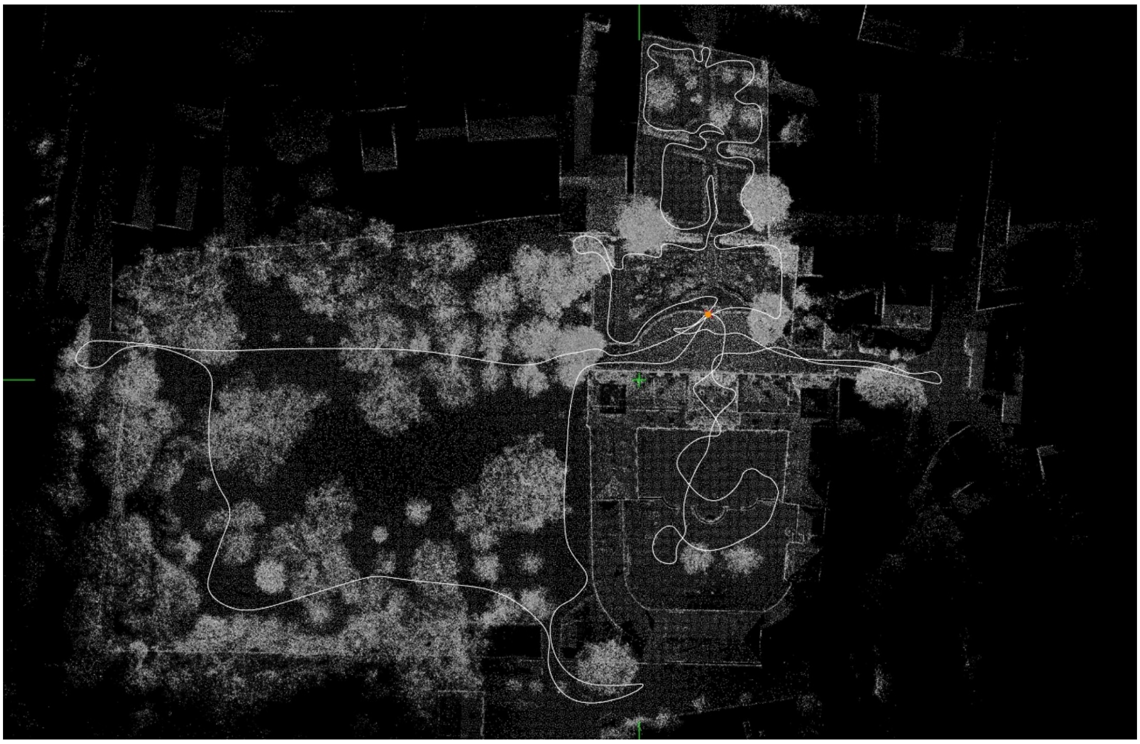


Fig. 95. Oberschwappach trajectories.

Survey planning

Reliable information is needed to assess the heritage landscape development status and to design management plans for its maintenance and conservation. The following report introduces a set of test datasets related to the documentation of landscape and architecture. The device tested might also face a challenge in large-scale landscapes. *Why was a digital recording developed?* Digital survey gives us a technical and objective output, while a traditional survey, with total station and drawings, tended to be subjective, charged of the author ideas and preconceptions.

"A short time spent route planning will ultimately save time in the long run and will give you the greatest chance for the best quality scan".[1] According to it, as soon as we arrive on site, we assess the environment to better design the survey: in terms of path planning. The area of scan in both case studies was large, so was necessary to pre-plan the survey, breaking down the scans into sections, trying to not walk longer than 15 minutes per scan.

We design and define the route plan – trying in all cases, to close the loops and if possible, to have at least three commons references point in the different scans. We anticipated some complications or challenges, as difficult spaces to walk and moving objects, like people and cars. For interior spaces, we plan to move as group, the surveyor with the scanner and the other member of the team opening the doors. During the planning it was considering that the first case study was a home for senior people, it was important to do not disturb or interrupt their routine. So, the interior recording was as fast as possible, conscious that we sacrifice the quality of the final output for interiors, but in any case, respecting the purposes of the survey. The interior was not the main objective of the survey.

The acquisition campaign was organized in two working days, to guarantee the possibility to verify the first day acquired raw data. Quality control to resolve eventually problems during the acquisition. After the first day, once controlled the raw data we proceed with the planning of the second day acquisition.

Data capture

The hand-held part of the device (1.49 kg) includes a VLP-16 (Velodyne LiDAR Inc., Morgan Hill, CA, USA)[2], a Firefly 8s camera with 4k resolution[3], an inertial measurement unit (IMU), a handle, and a reference plate[4].

The VLP-16 (0.83kg) has 16 channels and uses TOF LIDAR technology to measure up to 300,000 points/s in single return mode within a maximum range of 100 m. The distances measured with a continuous wavelength of 903 nm and a range accuracy of ± 3 cm. The FOV of the VLP-16 is 360°x30° with a vertical angular resolution of 2° and a horizontal angular resolution of 0.1°- 0.4°, and the internal rotation rate is 5-20 Hz. The VLP-16 is attached to the ZEB Horizon by revolving housing that rotates around an axis orthogonal to the internal rotation axis of the VLP-16. The combination of the internal and external rotation results in an angular FOV of 360°x270°.[5]

[1] https://geoslam.com/academy/project-preparation/ (last accessed March 2021).
[2] https://velodynelidar.com/products/puck/ (last accessed March 2021).
[3] https://www.fireflycameras.com/pages/firefly-x (last accessed March 2021).
[4] https://geoslam.com/academy/accessories/ (last accessed March 2021).
[5] https://velodynelidar.com/press-release/velodyne-geoslam-sales-agreement-zeb-horizon-mobile-sc/

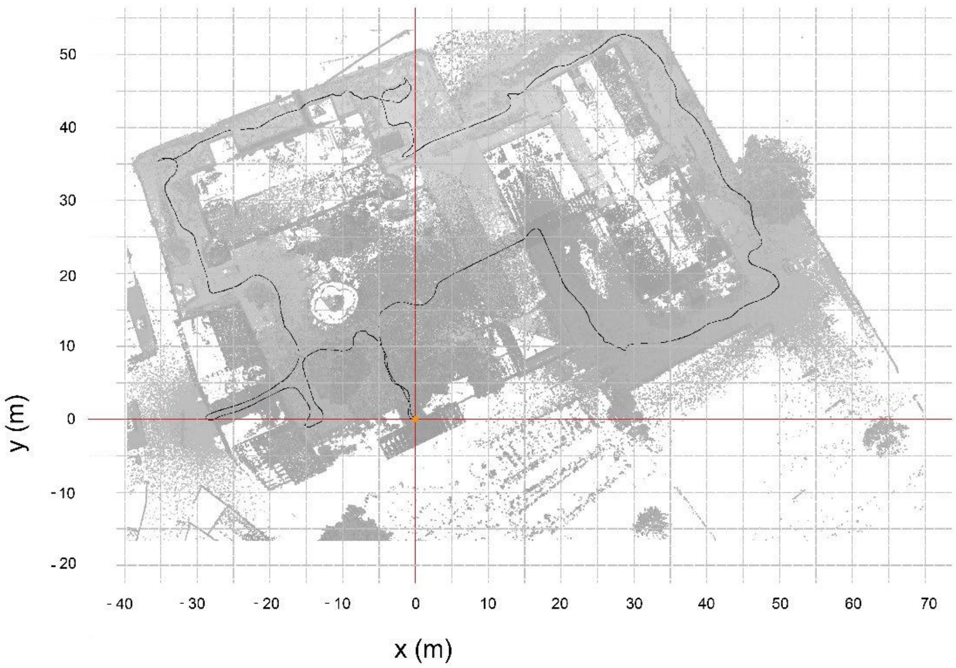


Fig. 96. One loop trajectory of Mainstockheim Ebracher Hof.

```
2020-10-16 12:27:03,124 [0x7f62b34cd780] INFO  Revo2Logger - ZEB SCANNING
2020-10-16 12:27:03,519 [0x7f629a7fc700] INFO  Revo2Logger - SBC Video start time:1602847623519
2020-10-16 12:29:50,506 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-26-48_0.bag
2020-10-16 12:29:50,544 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-29-50_1.bag
2020-10-16 12:33:13,137 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-29-50_1.bag
2020-10-16 12:33:13,170 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-33-13_2.bag
2020-10-16 12:37:30,628 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-33-13_2.bag
2020-10-16 12:37:30,678 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-37-30_3.bag
2020-10-16 12:42:07,582 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-37-30_3.bag
2020-10-16 12:42:07,626 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-42-07_4.bag
2020-10-16 12:46:08,440 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-42-07_4.bag
2020-10-16 12:46:08,485 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-46-08_5.bag
2020-10-16 12:49:44,583 [0x7f6298ff9700] INFO  Revo2Logger - Closing /scans/2020-10-16_12-26-48_2020-10-16-12-46-08_5.bag
2020-10-16 12:49:44,624 [0x7f6298ff9700] INFO  Revo2Logger - Recording to /scans/2020-10-16_12-26-48_2020-10-16-12-49-44_6.bag
2020-10-16 12:51:55,922 [0x7f62b34cd780] INFO  Revo2Logger - ZEB DEINITIALISING
```

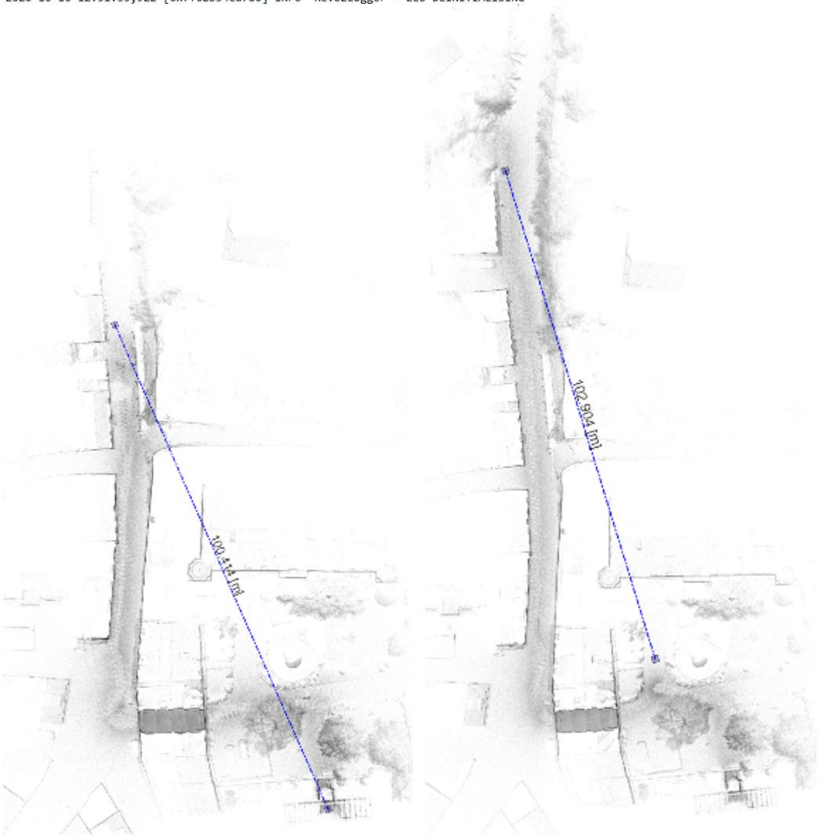


Fig. 97. Some recording issues in Mainstockheim Ebracher Hof.

The data logger (2.4 kg) contains the processing unit, a solid-state disk storage (120 GB), and the battery (operational time approx. 3.5 h); this is connected to the hand-held part via a cable. The size of the collected point data is approximately 100–200 MB per minute. A USB 3.0 port on the data logger is used to transfer the data to an external flash drive.

The workflow was similar to (Gollob et al., 2020), data acquisition with ZEB Horizon starts with IMU initialization, in order to establish the local coordinate reference system. The scanner was placed in the reference point (physically fixed as a color tape cross in a recognize place for about 10 sec. see Fig. 93). After approximately 15 sec. of initialization, the survey was executed by moving at walking speed, while the rotating scanner head captured data of the full 3D environment. The 3D data was stored in real time on the hard drive, located in the data logger in the proprietary compressed data format.

For data acquisition procedure the protocol and basic rules of the ZEB Horizon User Manual (GeoSLAM Ltd., 2019) has been respected. ZEB Horizon is IP 54 rated, and the environment was appropriate when using the system. Since the day was cloudy and with soft rain, a condition still acceptable for mobile mapping, it was necessary to wipe the scanner head before beginning the scan.

Respecting the walking trajectory in loops proved to be essential, as well as creating internal loops whilst scanning and when scanning multiple floors. Loops must be closed both horizontally and vertically to minimize the error. The longer the scan length without closing a loop, the more absolute error will be created. By closing a loop, repeated measurements are being made of the same area, and thus, the error is minimized (Figs. 94, 95).

In particular, the tested MLS tool, ZEB Horizon, having the ability to acquire images to color the point cloud, suits perfectly for surveying and documentation, even in Cultural Heritage fields. The algorithm[1] has the possibility to import information of color to assign to each point not only the XYZ coordinates but also RGB data.

To capture an adequate point cloud for colorizing, it was necessary to walk slowly directing the front of scanner to the object we wanted to survey (especially the facades). When transitioning to different spaces, we stopped, pointed the scanner in both sides of the transition area consecutively. According to the suggestions of GeoSLAM's support to increase video coverage and quality during the survey, we stopped for about 5 seconds every 1 minute.[2]

The observation was that colors need to be improved for the next surveys, that can be trying the integration with other action cams (such as GoPro) in order to capture more information about the color. ZEB Discovery face this issue.

Each start-end point was effectively marked on site (with a colored cross with tape on the floor). In our case studies, the main purpose signaled was the spread and visualization of results, the obtained results were appropriate. For the next surveys, a GNSS to georeferenced ground control points and to have an accurate control of the error, enhancing the accuracy of the point cloud will be employed.

The various paths length, approximately 5000 linear meters in the area surrounding the object of study took about 2 h and 50 minutes of acquisition for *Mainstockheim* case study. And the approx. 1000 linear meters for *Oberschwappach* case study took 30 minutes of acquisition.

[1] As explained in the features of the specific slam algorithm: post-scan colorization.

[2] https://geoslam.com/blog/2020/02/03/tips-and-tricks-zeb-cam/ (last accessed March 2021).

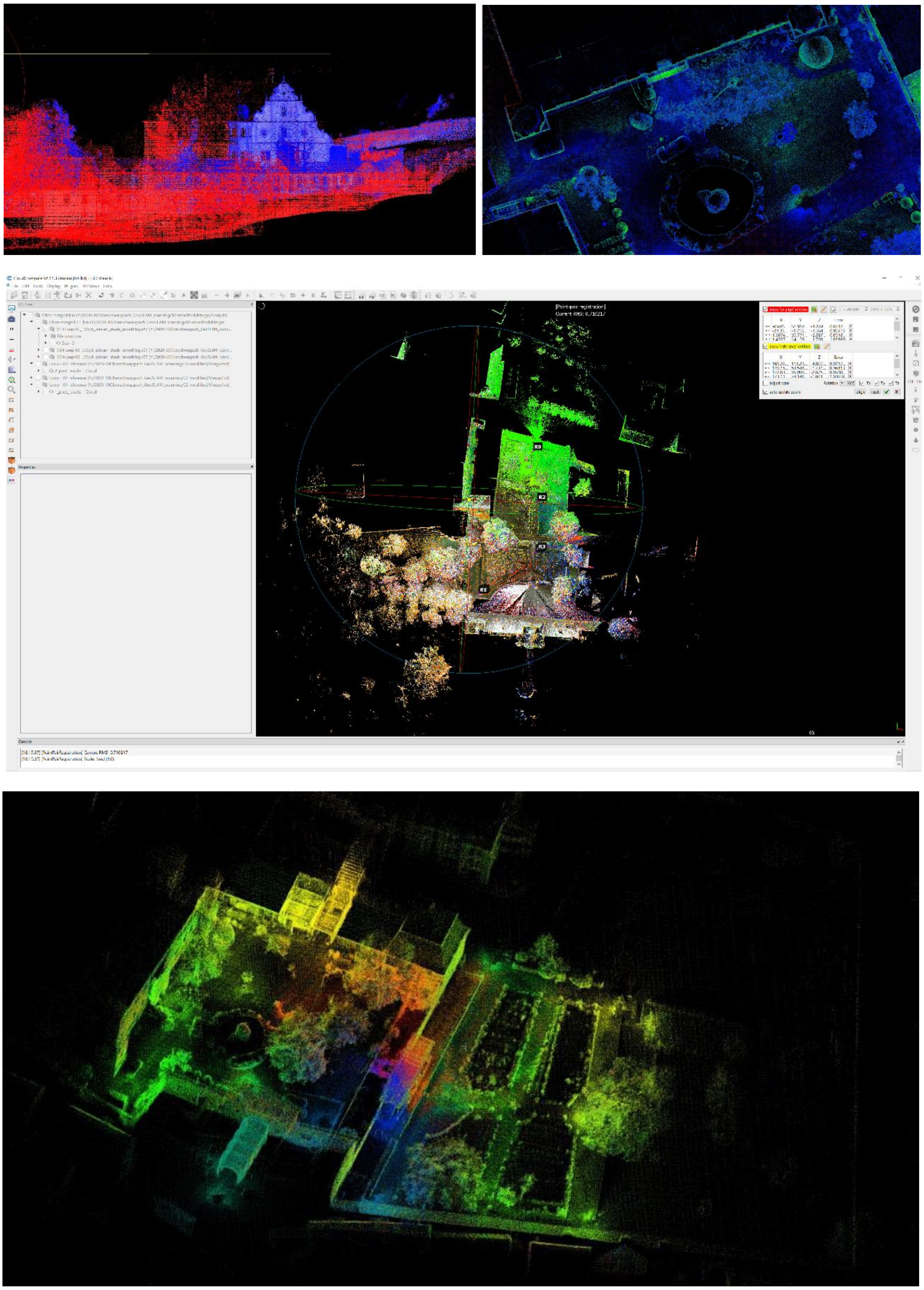


Fig. 98. Mainstockheim and Oberschwappach Ebracher Hof data processing.

The recording of all each loop took approximately from 7 to 12 min, depending on the possible walking speed and path characteristics. Using the accessory ZEB pano, it was possible to take 360° panoramic captures as equirectangular projection of the surveyed case study.[1]

Some operational rules for landscape survey: inspect the site in advance in order to remove any obstacles along the path; walk slowly during the scanning phase to have a better coverage between the data and a higher resolution; proceed as slowly as possible in the presence of relevant objects in order to allow the best possible alignment and data redundancy; divide long paths into more than one scan mission both to avoid large point clouds and to minimize the drift effect and therefore propagation of alignment errors; acquire large common areas between successive scans, so as to be able to evaluate eventual misclosure (Limongiello et al., 2020).

For next explorations the possibilities of the improved SLAM algorithm and chip computing capabilities can be tested**,** since a smartphone can deploy an online SLAM system, which allows the smartphone to perform the relative positioning in places without GNNS signals (Fan et al., 2020)**.** The quality of raw data with systems based on SLAM approach, more than any other solution, is highly dependent on how the acquisition campaign is conducted (as repeated in the previous case study).

Data processing

The raw data was transferred from the data logger of ZEB Horizon to a desktop computer of the University of Bamberg (128 GB RAM, Intel® Xeon® W-2125 CPU 4.01Ghz) using a USB flash drive. The data was imported in GeoSLAM Hub 6.0.1 software[2] and the data was processed automatically with the SLAM algorithm. A moving time window through the raw data was used for scanner location and to calculate the trajectory of the scanner, based on IMU data and feature detection algorithms. For the *Mainstockheim* case study has been imported 12 raw data files and for *Oberschwappach* case study 3 raw data files. To have reference of timing, for a 12 min loop takes approx. 45 min of processing. Registering of the point cloud was based on the distances and angles of the points relative to the scanner position, using a linearized model to minimize the error in the IMU measurements as well as maximizing the correspondences between the 3D point cloud data for each respective time segment (Gollob et al., 2020).

For *Mainstockheim* case study, the 12 loops acquired have been processed. Loop 01, a big loop around the back of the buildings, about 350 meters long takes 11 min 34 sec of acquisition and 45 min of processing to construct a point cloud of about ~87.61 million points (Fig. 96). For *Oberschwappach* case study, the 3 loops acquired have been processed. Loop 03, a big loop around the cloister of the buildings, about 200 meters long takes 6 min 16 sec of acquisition and 30 min of processing to construct a point cloud of about ~49.98 million points.

The focus has been on the point cloud that is particularly noisy or has a poor-quality result. For the exterior scans in general the slam algorithm gives an acceptable result as default. For the interior scans we have corrected some of the processing parameters of local registration. Convergence threshold (to 3 value, to increase the number of times the SLAM algorithm will try to match the data within an overlapping area), rigidity (+5 to increase the weighting on the IMU position) and maximum range (to limit the range of the scan data to 50 m to improve the quality of the point cloud). After correcting the parameters, it has been possible to see the reduction of the noise and the improvement of the quality of the point cloud. For *Mainstockheim* Loop 11 and 12 we have had some recording mistakes (Fig. 97).

[1] Panoramic captures will be used to create a virtual tour of both cases of study.
[2] https://geoslam.com/solutions/geoslam-hub/ (last accessed March 2021).

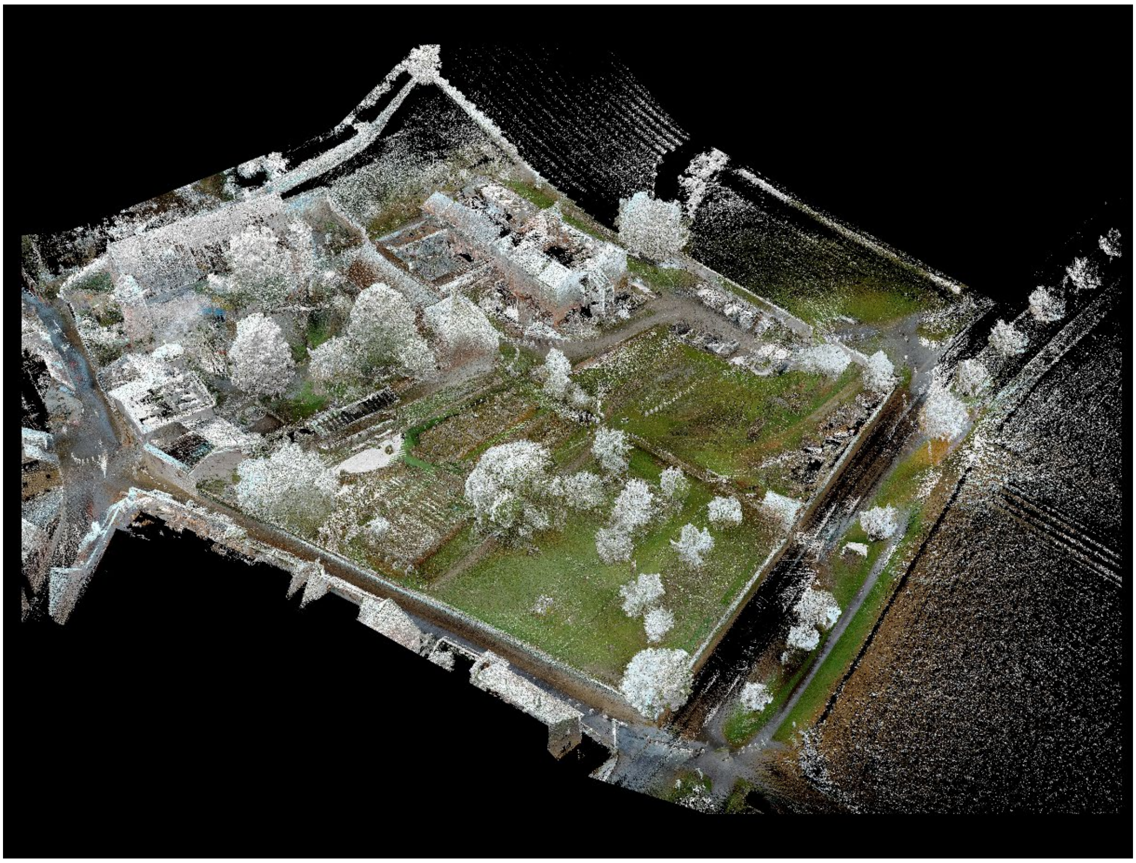


Fig. 99. Mainstockheim Ebracher Hof color point cloud.

Fig. 100. Oberschwappach Ebracher Hof color point cloud.

Probably we exceed the range of the scans, so the laser suddenly (and without any warning)[1] stopped recording. It was controlled in the data logger. We assume a lack of aligned features caused the interruption of the scan. The cause is a more natural setting in vineyard without fixed building geometry.

The raw data of Loop 11 takes 2 min 49 sec and only ~20.78 million points (the first signal that something was going wrong). For the reprocessing, the local parameters were corrected as convergence threshold, the rigidity, and the end processing early (since the scan stopped recording) and the start/finished closed loop was unticked.

Although both scans have been corrected, and partly recuperated and consulted with the GeoSLAM support, both scans have been discarded.

The next step was alignment and Merging, For *Mainstockheim* all the scans were roto-translated in reference to the loop 01 and for *Oberschwappach* all the scans were roto-translated in reference to the loop 03. Then merged, and subsequently imported in GeoSLAM Draw 3.0.4.

One of the bugs of the procedure: "Data alignment will always create separate files which are rotated in space. The alignment process does NOT produce a single output file" (GeoSLAM Ltd., 2020). Because after the merging the output to only a compressed LAZ file without information of color, to analyze the completed point cloud it was necessary to use other third-party software.

Processing in an opensource 3D point cloud processing software, CloudCompare (CC): For *Mainstockheim* the 10-point clouds were then simply roto-translated in space respecting the reference system of the reference cloud: Loop 01. Four points were selected in the reference point cloud and in the aligned point cloud to better improve the alignment. For *Oberschwappach* the 3-point clouds were aligned in reference to the loop 03 (Fig. 98).

The *Mainstockheim* complete point cloud had over ~723 million points with a density of approximately x pt/m, the weight is 15 GB. It has been sampled in CC (0.01) resulting in ~366 million points of 6.5 GB and (0.05) ~35 million points of 700 MB (Fig. 99).

The *Oberschwappach* complete point cloud had over ~183 million points with a density of approximately x pt/m, the weight is 3.25 GB. It has been sampled in CC resulting in ~40 million points of 744 MB (Fig. 100).

To determine the effectiveness of the alignment and filtering procedure, it was decided to produce some cross sections along the point cloud. In the areas with a lower density of points - due to the formation of rapid shadow cones during the acquisition - there are gaps of information. This is a valuable experience for later processing. The maximum value of the RMS for the discrepancies between matching points on all the registration pairs is about 3.5 cm.

According to Table 9, the relative accuracy of points obtained by the ZEB Horizon is ± 30 mm in the registered point cloud under normal lighting conditions i.e., daylight. The registered point cloud is given in a local coordinate system, with origin at the start/end position of the walking path. The data for each of the ten loops for *Mainstockheim* and three loops for *Oberschwappach* were exported in the E57 file format. For exporting, the parameter settings '100% of points, time stamp: scan, and point color: zebcam+shaded and smoothing' were selected in GeoSLAM Hub 6.0.1. For example, Loop 01 of *Mainstockheim* of ~87.61 million points export a file of 900 MB and Loop 03 of *Oberschwappach* of ~49.98 million points export a file of 500 MB.

[1] That is an issue that need to be improved in GeoSLAM ZEB Horizon.

Fig. 101. Mainstockheim Ebracher Hof point cloud orthographic projection.

Fig. 102. Oberschwappach Ebracher Hof point cloud orthographic projection.

Results

After the Acquisition phase, it was possible to extract information for the next phases of CAME methodology for different purposes. 2D output such as, orthoimages, plans, sections, etc. with the possibility to analyze the output, i.e., measure area, distances, etc. 3D output, such as, point clouds, mesh, 3D model, HBIM, etc. Taking advantage of the compatibility between the E57 format with others software, it was possible to explore the point cloud and to generate animations in Autodesk Recap and Cloud Compare (Figs. 101, 102).

Furthermore, for the case studies an animation in Adobe After Effects, as storytelling with purposes of dissemination and awareness campaign was produced. It was a video of impact to be disseminated in social network. It has the aim to promote direct participation of protection community but scientifically accurate, that explains the value of remains, the heritage, the importance of not to touch historical evidence. To support training to young people: scientific methods, techniques, possibilities and to make the heritage accessible to everyone. By virtualizing these Cistercian Landscapes and disseminating this project through social media, direct involvement of participants in the community is encouraged (Fig. 103).

Involving communities in this way helps to make them more aware of the need to protect the site and reinforces the sense of collective belonging to the territory. Heritage, in its many forms, is not only a representation of the past, but a connection or reconnection with a past that is active and alive in the present. Heritage shapes and reshapes people's sense of place, sense of belonging and cultural identities at the local and national level. It is what brings people together.

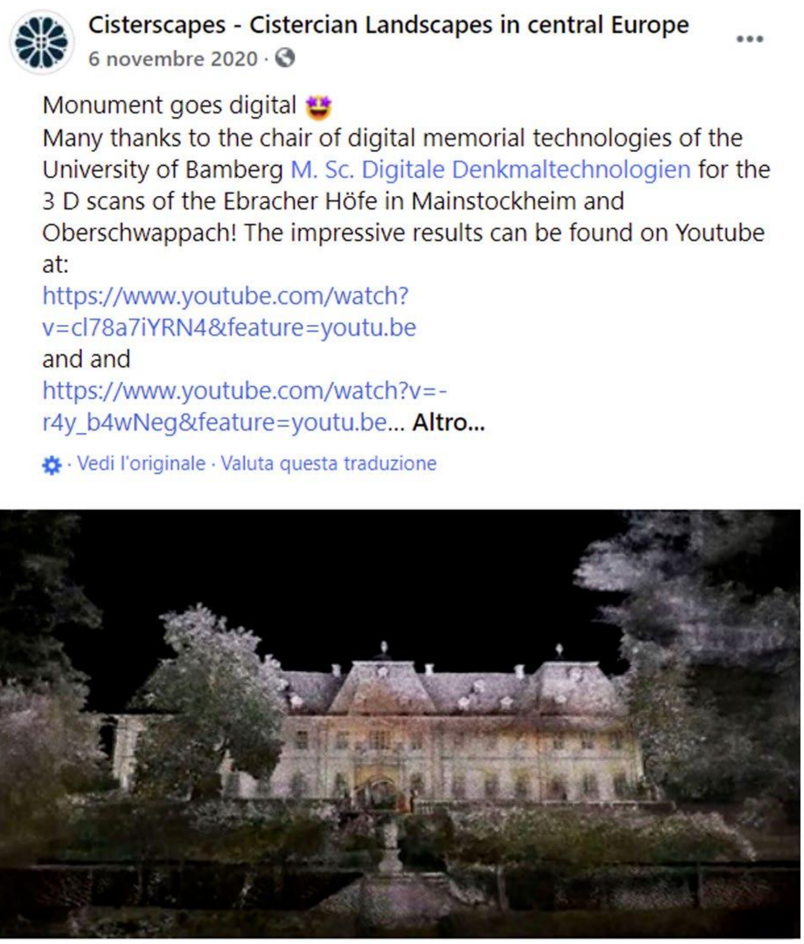


Fig. 103. Cistercian Landscapes awareness video in social networks.

6.2.3. Considerations

In today's complex world, keeping at pace with the speed of change is a challenge for all professionals in any industry. In the field of the digital conservation of Cultural Heritage we are continuously dealing with new technologies. Even more, with the ultimately trends of 2020, during the pandemic lockdown and travelling remotely, digital documentation becomes a tool for education, enjoyment, and hope for the society (Hess et al., 2019).

One of the major advantages of applying MLS, in the case study GeoSLAM ZEB Horizon, was rapid data acquisition over the entire site. With a maximum number of 300,000 points/s and a maximum range of 100 m, the GeoSLAM ZEB Horizon is suitable to capture the geometry of the surroundings. However, this requires further research. The case studies served not only to generate an accurate output to be explored in the Cistercian Cultural Heritage Project, but as a test of the instrumentation to ascertain the best practices of the instrument.

In the field of CAME methodology next step is to integrate the data acquired with the previous survey that serve as a technical documentation for the restoration of one baroque stair of the garden, support for European Heritage volunteers[1], to organize the graphic documentation and synthesize it on a proposal platform for the exhibition, for instance, historical accuracy database with timeline. The idea is to extend the methodology to other case studies in the same field, such Ebrach Abbey and gardens: to still contributing to Cisterscapes project - *Cistercian Landscape Connecting Europe* (Fig. 104).[2]

Fig. 104. GeoSLAM recording in Ebrach Monastery. Photo by Mona Hess.[3]

[1] https://www.heritagevolunteers.eu/en/ProjectsByTopics/TraditionalStoneTechniques/RestorationOfArchitecturalElementsInAHistoricGarden? (last accessed March 2021).
[2] https://geoslam.com/blog/2021/02/19/creating-a-digital-twin-of-cistercian-landscapes/ (March 2021).
[3] The recording of Ebrach Monastery, gardens and surroundings took place on 26 March 2021.

Sería tener una opinión muy baja de los antepasados, suponer que todo este trabajo inmenso y minuciosamente exacto y detallado, hecho con concienzuda perfección, tenía como única finalidad el servicio de una superstición primitiva o un culto estéril de los antepasados.

María Reiche Grosse Neuman.

6.3. A case study of an Ancient Territory in South Africa

6.3.1. Introduction to Moxomatsi (25°43'19.2"S 30°17'29.5"E WGS84)

The settlements and terraces, in the province of Mpumalanga, represent an extraordinary archaeological testimony of South Africa (Fig. 105). Long before the arrival of the European colonisers, these environmental engineering works were constructed around the 1650 by the Bokoni, an extinct African community, not only to provide shelter in its most primitive form, but also to assist in food production in the most 'innovative' way (Delius et al., 2015). The need to preserve the traces of a civilization that has now disappeared led researchers, from the University of Salerno and Tshwane University of Technology, to collaborate in a project using CAME aimed at disseminating of knowledge. This third and last case study, summarizes the activities carried out in a project funded by the Italian Ministry of Foreign Affairs and International Cooperation *"A Social and Spatial Investigation at the Moxomatsi village, Mpumalanga (SSIMM)"* which attempts to recover the archaeological site and recognize its deserved value of Cultural Landscape.

Fig. 105. Overview of the Moxomatsi site, Mpumalanga. Photo by Alex Schoemann.

6.3.2. CAME Methodology application

CAME methodology was implemented to experiment with acquisition surveys as a starting point for an architectural project which helps to enhance and preserve the site (Fig. 106).

Fig. 106. CAME - workflow implemented in Moxomatsi.

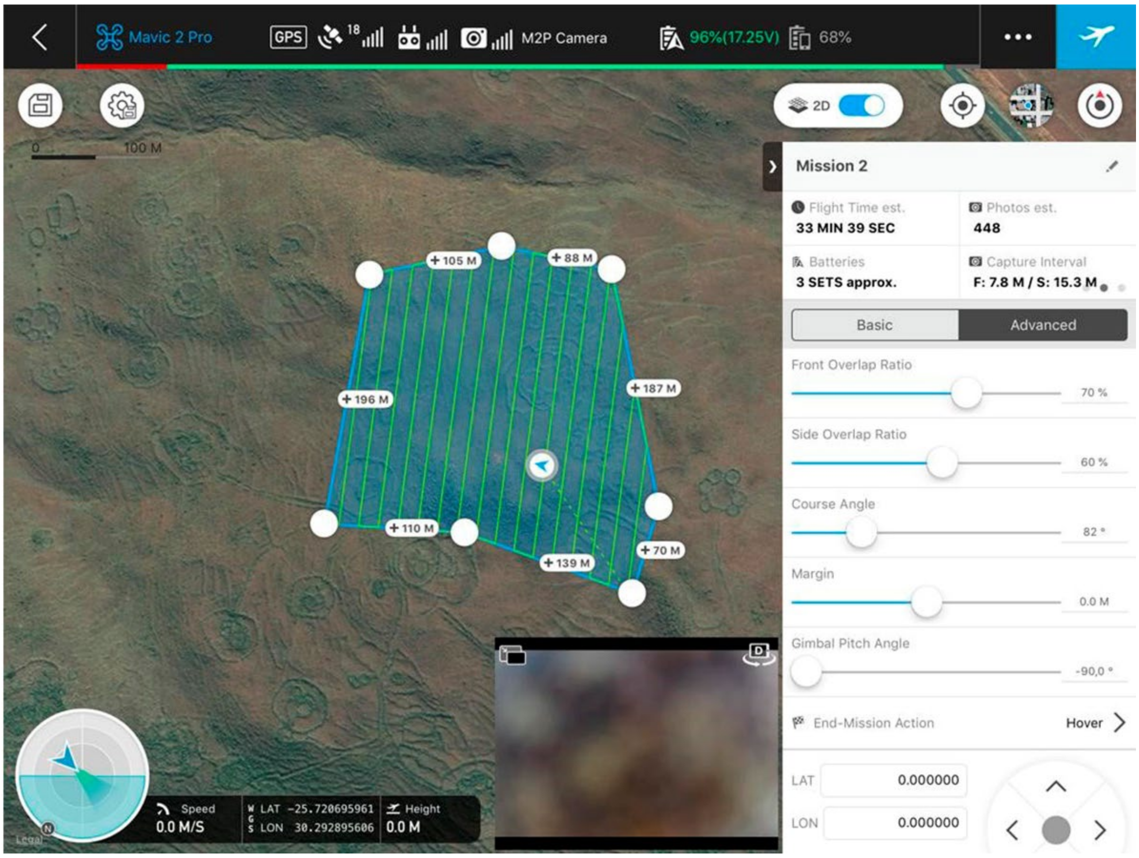


Fig. 107. A flight plan of the DJI Mavic 2 Pro in Moxomatsi.

Fig. 108. The GNSS Spectra Precision 60 and the DJI Phantom 4 in Moxomatsi.

Survey planning

Based on the characteristics of the site, according to the methodology implemented, it was decided to construct the 3D model through image-based techniques, acquiring the images with a UAV photogrammetric approach (Fig. 107). DJI Phantom 4 (Table 11) and a DJI Mavic 2 Pro (Table 12) were employed.

Sensor	1/2.3" CMOS – 12.4 M effective pixels
Lens	FOV 94° 20 mm /24 mm - f/2.8
ISO Range	100
Electronic Shutter Speed	1/765 s
Resolution	4K
Frames per Second	30
Operating Temperature	0 °C to 40 °C
Stabilization	Gimbal 3-axis (pitch, roll,yaw)
Weight	1.38 kg
Diagonal Size	350 mm
Max Flight Time	Approx. 30 minutes

Table 11. DJI Phantom 4 specifications.

Sensor	1" CMOS sensor - 20 MP
Lens	FOV 77° 28 mm - f/2.8
ISO Range	50
Electronic Shutter Speed	1/765 s
Resolution	4K
Frames per Second	30
Operating Temperature	0 °C to 40 °C
Stabilization	Gimbal 3-axis (pitch, roll,yaw)
Weight	0.5 kg
Diagonal Size	350 mm
Max Flight Time	Approx. 30 minutes

Table 12. DJI Mavic 2 Pro specifications.

For the georeferencing of the model a Spectra Precision SP60 was employed (Table 13). It features integral long-range Bluetooth technology that functions over a 100 m radius. The SP60 is compatible with many data collectors, such as the T41 and the Ranger 3, for extended power and precision. It is compatible with different software such as Survey Pro, FAST Survey, and ProMark Field (Fig. 108).

Channels	240 channel 6G ASIC
Accuracy	15 mm ± 1 ppm (rms) static vertical
Module	410 MHz to 470 MHz
Bluetooth	Device class I
TNC connector	UHF antenna
Operating Temperature	-40 °C to 65 °C
Weight	0.93 kg
Dimensions	Height 70 mm ø 210 mm
Operating time	8-10 h
Protection Class	IP67

Table 13. Spectra Precision 60 specifications.

Fig. 109. The MAPIR Survey 2 NIR camera in Moxomatsi.

Fig. 110. Orthoimages and trace analysis of Moxomatsi.

Data capture

With the DJI Phantom 4 only nadiral images were captured, the flight plan was organized with dual grid. Thus, 198 images (99 for each grid) were acquired, detecting a territorial extension of about 5 ha, whose centre of gravity coincides with the pattern on which photogrammetric experiments were conducted with telescopic system. The flight plan was designed considering the general requirements of the project - for instance, a minimum GSD of about 2 cm - and with the aim of ensuring a high level of automation in the subsequent data processing phase. The first nadir grid was developed from East to West, with an average flight height of 45 m, medium speed of 3.8 m/s, overlap of 70% and sidelap of 60%. The second nadir grid developed from South to North, with the same average flight altitude, medium speed of 4.2 m/s, and constant overlap and sidelap. Even with the DJI Mavic 2 Pro only nadir images with flight plan in a double grid were captured (Fig. 107). In this case, 448 images were acquired (224 for each grid), recording the same area: the higher number of images compared to the previous overflight is due to a lower flight height (30 m instead of 45) and a reduced FOV (from 94° to 77°). According to the previous grids, the UAV speed was of 4 m/s, for a design GSD of aprox. 7 mm. Finally, a NIR (Near Infrared) sensor installed on the DJI Phantom 4 was tested. The relative flight mission, planned to cover the area with sufficient longitudinal and lateral overlap (i.e., overlap and sidelap), made it possible to simultaneously record the NIR and RGB data. For the acquisition of this information, Mapir Survey 2 (Fig. 109), with 1/2.3” CMOS sensor, 12 MP resolution (pixel size of 1.34 micron) and 4 mm focal length, were implemented. The frames were captured in aperture priority (with f/2.8), variable shutter and constant ISO at 200, according to a path identical to previous flight plans, but single rid, with a flight height of 30 m, average speed of 3 m/s and time-lapse mode (at 2-second intervals). Photogrammetric data acquisition was supported and combined with GNSS positioning techniques. In this test it was proceeded to the diachronic measurement, in NRTK mode, of a network consisting of 16 artificial targets placed on the ground (flat forex panels, with a size of 40 x 40 cm, fixed by means of topographic nails). The instrumentation used to measure each target consisted of the receiver SP 60, to verify the propagation of errors and for the precise georeferencing of the survey by UAV.

Data processing

The data collected in the acquisition campaigns were processed in Agisoft Metashape. The workflow used is what the current literature presents as best practice, similar to the first case-study of presented on this Thesis (UAV-data processing). In this case study, particular attention was focused on the optimization phase of camera orientation, both regarding the implementation of GNSS geo-localization data and the tie points filtering. With regards to the latter aspect, two parameters have been considered, the first the number of images and the second the reprojection error. To reconstruct the 3D position of a tie point, this must be visible in at least two images; in this case, however, the positioning accuracy would be very low and for that reason only the points visible in at least 3 images have been retained. Regarding the second parameter, the reprojection error, which is expressed in pixels and represents the distance between the point on the image where a reconstructed 3D point can be projected, and the original projection of that 3D point detected on the photo which is used as a basis for the 3D point reconstruction procedure; for the case study all tie points with an uncertainty greater than one pixel were discarded.

Fig. 111. Proposal for a social architecture in Moxomatsi using as a basis the 3D survey.

Results

For a general assessment of the accuracy of photogrammetric models, data acquired with GNSS systems were used. In detail, the artificial targets detected were divided into two groups, ensuring for each one a good distribution in the scene. The first group, containing the GCPs, was directly used in the process of optimizing the orientation of the cameras. The second, containing the QCPs (Quality Check Points), was employed to quantify the distance between the input source and estimated positions of the markers. In the case study, the maximum deviation recorded on QCPs is about 6 cm, while the average error is less than 3 cm, comparable with the pixel resolution obtained in the orthoimages (Fig. 110).

The data collected in the acquisition phase was processed to build a repository to support the next modeling phase. In this phase, finally, the aim was to propose a design hypothesis for the recovery and enhancement of the archaeological site. Starting from the topographic surface previously surveyed, following the guidelines towards the design of a sustainable architecture, an architectural proposal was designed for the creation of a multifunctional center for interpretation, dissemination of historical knowledge and local cultural memory, that is, a space destined to become a new regional socioeconomic fulcrum. For this purpose, the output products from the Agisoft Metashape environment were used as the orographic basis for the modeling. The data have been implemented in effective parametric modeling software, such as Rhinoceros, Autodesk Revit, and Lumion 3D, in order to generate a realistic and metrically accurate topographic surface of the site, in which to insert the different design solutions for the structures of the information center. In response to the existing organic configuration of the site, the final design responses a contrast using straight lines with contemporary approach. The final presentations included conceptual drawings, plans, sections, and a video rendering (Fig. 111).

6.3.3. Considerations

The result is a 3D digital reconstruction of the Moxomatsi archaeological site that can be compared with the available knowledge and exported for two purposes: planning of interventions and dissemination of expertise. The proposed project is aimed at seeking new ways of protection and fruition of the heritage. In particular, the photogrammetric surveys prove to be effective tools for morphological and geometric reconstruction and an essential support for an interpretative analysis of architecture and landscape. They represent a rigorous reading instrument, a support to historical analysis, which lays the foundations for projects of restoration, protection, conservation, monitoring and enhancement of the heritage. In order to guarantee an adequate result of the survey, it was necessary to establish a rigorous methodology from the acquisition campaign to the data processing and subsequent dissemination of the results. The advantage of such a workflow is to enhance the potential of the classic graphic designs, with the output useful for an assessment of landscape compatibility with the existing buildings, in detail the circular traces of dry stone, evidence of the ancient residential settlement of the Bokoni tribe. The case study demonstrates how a correct technical-scientific approach can simultaneously protect, interpret, and document cultural landscapes, including those unjustly and long forgotten due to poor documentation, knowledge and unfavourable socio-economic factors. The workflow operated identify new frontiers for heritage documentation.

To live in hearts, we leave behind is not to die.

Thomas Campbell.

7. RESULTS

The applied methodology has provided a 3D database of three different typologies of case studies, World Heritage Sites. The first, more complete, managed to obtain a management tool for an emblematic historical architecture in Italy, the second, more synthetic, applied to two case studies in Germany to promote the knowledge and dissemination of the cultural landscape; while the third one synthetic as well, applied to a territorial case study in South Africa to digitalize the site and used it as basis for an architectural project.

This methodology obtained results, which will serve, for academic purposes, to share practices and techniques for capturing, processing, and disseminating data on Cultural Heritage; for operational purposes, such results will be a useful resource for those responsible for the management of these cultural sites; they will also serve for scientific purposes, as reliable documentation of these case studies in case of need or loss of cultural memory.

CAME has made it possible to capture extensive 3D data sets that have become the closest link to the object, its 'digital reality'. This digital reality is a tool that provides accurate information about the case study, ensuring that decisions are based on concrete data. Through the creation of 3D models, with high geometric and informative precision and visually similar to the case studies, we will continue to innovate in terms of documentation, conservation, and fruition of Cultural Heritage.

The realization of this work has involved an exhaustive study, mainly of the first case study. By using the HBIM format, it has been possible to start structuring all the architectural information of the building, from its origin to the present day.

The substantial contribution is the possibility of storing in the same 3D database all the successive phases of transformation, i.e., interventions that can be carried out on the case study itself. This database can be constantly updated with new information, thus promoting effective Cultural Heritage management.

Retrieve information, organize it, and disseminate it; for the construction of a photo-realistic scale model of the case study. This model does not seek to simply replicate reality, but to add other values, creating effective communication through interactive strategies. It seeks to move towards greater cultural participation, transforming the way in which cultural content and values are perceived.

The 3D digital model makes it possible to examine the case studies, navigate, section, analyze, measure, and compare the heritage in a way that would not be possible with the actual physical object. This allows everyone, from anywhere, at any time, to experience the Cultural Heritage. From the perspective of sustainable development strategies, these results also allow a pedagogical exploration of heritage from a unified and accessible source of information. It becomes a useful tool for the analysis and historical-scientific interpretation that disseminates, at the same time, these cultural contents in virtual environments breaking down physical and digital barriers.

The presented work managed to add a further step in terms of virtualization and visualization by creating an immersive VR system that not only allows the classic virtual tour of the object, but also provides the technical information coming from the BIM system. The graphical user interfaces allow data to be easily incorporated directly into the BIM environment, simplify the use also for non-AEC experts and make collaboration possible between the many figures involved in the conservation process, such as architects, art historians and restorers, among others.

Fig. 112. Projects network throughout the doctorate thesis.

It is important to highlight the evolution of these technologies during the process, from the beginning of the Thesis in 2017 until now. In the process, the numerous limitations of incompatibility between different software tools have been overcome. It has been necessary to consider the format of the files obtained, and the amount of information to manage the project. According to Letellier (2020) the gap between people working in heritage conservation and those who generate that information to document it is getting wider. One consideration will be to archive the results obtained in a compatible format for their sustainability over time. Innovations generate a much richer and multidimensional documentation, but at the same time they also difficult the conservation of this documentation. For instance, advances in capture technologies allow the accumulation of a large archive of data on Cultural Heritage; yet, in the academic community there are still concerns about its durability over time, its use, and its accessibility. Conservation tends to maintain the current state of an object, and the technology for documenting it is evolving rapidly. In this Thesis it is expected that the data obtained, in the near future, will be accessible and reusable by the community.

Digitization and the use of emerging technologies, such as extended reality (virtual, augmented, or mixed) can interact with these new forms of digitization to achieve an immersive cultural experience. This will allow communities to participate in the process of protecting their heritage, also and especially the minor, knowing it and preserving it in order to pass it on to future generations.

The visualization and communication of heritage has been essential in the process throughout the Thesis. It was sought to generate a much more visual and intuitive interface to the database, leading to new uses related to the analysis of heritage information, as well as tourism and educational applications based on the model. Digital design tools have the potential to let people participate actively in the cultural environment and interact directly with it. Using simulated experience, the human experience of a situation using computer technology will potentially be like a walk through the real situation.

Digitization in the field of Cultural Heritage is very relevant. It can provide a more powerful dissemination strategy, raise awareness, spread the importance and creative connection with the intangible values of a heritage, while increasing visibility, to access a larger number of users. Digitizing objects and designing new tools to explore and analyze Cultural Heritage not only increases the user's sense of presence in this artificially created world, but also allows the heritage to be perceived from different perspectives. Technology provides the tools to finally break down this 'barrier' and establishes a relationship based on communication, which has been unidirectional and passive, for too long, with an active involvement of the community. The latter has extremely positive implications towards an involved protection of Cultural Heritage. Stimulating the feeling of 'presence' i.e., the cognitive phenomenon where people feel as if they are physically present in the virtual world, an incredibly powerful sensation, and an almost exclusive recreation of extended visualization technologies.

Technologies should be a tool to improve people's quality of life through the dissemination of history, recovering values. With an effective use of such technologies, it is possible to spread the Cultural Heritage, to take it out of its physical space to add it to a virtual space, and to be able to investigate it. Online communication, specifically through social networks, is an essential tool for disseminating content and gaining access to new audiences. Its use has made it possible, on the one hand, to approach new generations and, on the other, to increase the visibility of the project. This methodology has sought, therefore, to deepen the knowledge of the objects, to interpret the past, to transmit it to the future, while recovering as much information as possible to communicate the history and to disseminate it to future generations. Moreover, it aims to encourage potential new users to perceive architecture in a new way, beyond space and time (Fig. 112).

"A monument does not disappear when it is damaged or destroyed, but when it can no longer be remembered…". [1]

[1] Personal adaptation of *"Vita mortuorum in memoria est posita vivorum"* by Marcus Tullius Cicero, 106-43 a.C. and "*Nessuno muore sulla terra finché vive nel cuore di chi resta*" by Sant'Agostino.

8. CONCLUSIONS

In this work, a methodology for the extended fruition of historical heritage has been implemented and extended, with different levels of detail, in three different typologies of Cultural Heritage. The experiences show that it is a tool with great potential which allows a virtual reconstruction of the sites, providing a valid technical and scientific support. It is also an effective means to transform the state of knowledge of a given object, and to communicate the research to a growing audience of potential users.

It is a high-performance tool that allows a virtual reconstruction of precise architectural objects and sites. It provides as-built documentation that offers a valuable support tool for restoration projects and is an effective means of transforming the current state of research on the cases studied. It also serves as a basis for communicating the research to a wider public - and thus to achieve greater community involvement and encourage heritage protection.

Furthermore, in order to guarantee effective protection and safeguarding actions, it is increasingly important to deepen the knowledge and characterization of the object of study: the restitutions have been extraordinarily effective to provide direct documentation of its entire history. The study, filtered by the scientific rigor of a correct architectural study, will allow to verify the coherence between what the specialized literature affirms and what the analyzed objects of study reveal.

Therefore, an infographic product will be restored for the development of documentation for a potential responsible and sustainable conservation, allowing to reveal both to specialists in the sector (architects, engineers, archaeologists) as well as to the whole community, what is still hidden, even though virtual models. This will be a different way of representing and communicating the places, even to those who do not know them, generating a real cultural promotion plan. All of this will be reached through documentary research and integral techniques of survey and analogical and digital processing, based on a study of the site with scientific rigor.

This will develop new methodological experiences to deepen the state of knowledge of sites of inestimable value, addressing in an interuniversity and interdisciplinary way, topics from different areas, such as the survey and history of architecture, archaeological research, architectural restoration; among other diverse, but at the same time, adjacent disciplines. In this way, by adequately combining the contributions of the aforementioned sectors, a single general objective will be pursued: to represent, reconstruct and reread the real value of heritage.

All of us have much to learn from our shared past and technology is changing the way we can do it. The experiences demonstrate the potential of the methodology, from the use of new survey technologies to the digitization of three-dimensional models; it can be used to create new educational experiences and propose new ways to promote not only tourism, but also education and knowledge. If necessary, it is a tool that can also be used for either a visit 'in Covid times', or for educational purposes, and certainly to promote knowledge.

VR and digital modeling make it possible to recreate places that are not accessible to people, allow a realistic immersion in digital environments that would not be normally explored, enable a huge amount of content to be shared through a 3D digital reconstruction, and improve the level of interactivity and knowledge of different types of users, from professionals to virtual tourists and students. In addition, scientific data allow to easily create tools for didactic purposes, cultural objects can be 'enhanced' in value in order to engage a wider audience and to develop new and innovative models of fruition.

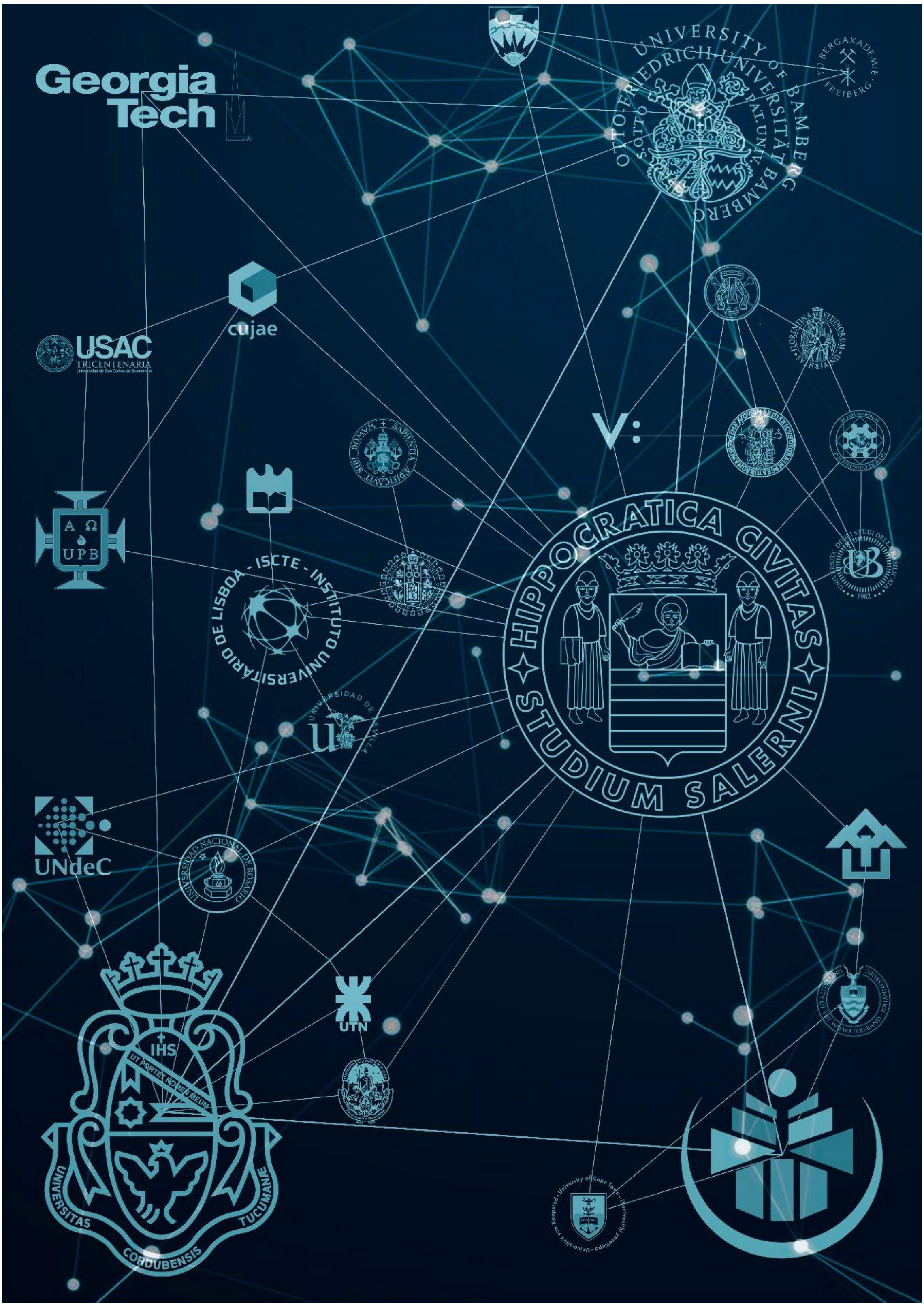


Fig. 113. Universities network throughout the doctorate project

The product becomes a tool at the service of historical and archaeological research where the most varied historical reflections and the possibility of comparing them with another knowledge can be materialized. Through these new ways of enhancing and making architecture known, the aim is to involve more and more types of users, to encourage, sensitize and motivate them to take an interest in the historical object. Virtual experiences have the potential to involve and engage visitors with an emotional connection, which lengthens memory retention (Lord 1999); this happens because, since forever, people have been looking for meaning, striving for memorable and authentic experiences.

These innovative visualization methods not only provide a scientifically valid basis but represent one of the most powerful means of dissemination, laying the foundations for an extended fruition of Cultural Heritage. Digitization and the use of emerging technologies can create new forms of cultural experience. This will allow communities to participate in their heritage, to generate a sense of belonging and meaning around it, and thus to know it, preserve it and pass it on to future generations.

In fact, if on the one hand such technologies facilitate understanding as they produce results using new communication languages, on the other hand, they improve the study of the experts due to the accuracy of the data they provide. It is essential to have a faithful record of the current state of the monuments to serve as a basis for promoting future interventions. The digitization of Cultural Heritage can be a fundamental tool in the current work of conservation, renovation, study, and promotion of cultural resources.

When a Cultural Heritage object is located in places that are not easily accessible for some reason, a digital model may be the best way to make the experience of a visit possible. These reasons can be varied, such as danger to visitors, in times of war; temporary closure for restoration work; the impact on a fragile environment of a massive public presence; inaccessibility of the site; cost or time constraints, which make it unfeasible for a particular person to visit a site; or perhaps closure restrictions due to a pandemic affecting the whole world. Heritage in digital, enhances the understanding of the site and generates new experiences. In any case, the virtual model does not replace the original, but complements it.

Cultural Heritage is an essential part of our future. It is part of our identities, of our cities and regions, of our emotional sense of belonging, and it is essential for sustainable development. The goal was to create a digital heritage that bridges the past and the future. Because, according to Criado-Boado in his 25th Annual Meeting of the European Association of Archaeologists "there is no other way to commemorate the past than by looking to the future, looking forward. The vision of linear time that has been instilled in us identifies the past with what is behind us and the future with what lies ahead. The future is where we are going, and we see it ahead. But the past is what allows us to go there. When we look ahead, space and time fold before us to superimpose the past we were and the future we want to be. In fact, cognitive science knows that the sense of sight has at least as much to do with memory as with the visual perceptual stimuli we receive. It is not that the past comes back: it is that it was always there". In difficult times, culture plays an essential role for individual and collective well-being. Hence, investing in Cultural Heritage means investing in well-being, and improving people's quality of life.

As future developments, work is underway to unify the database and publish it to make it accessible to all. Organizing the information to be available online will make it possible to maintain public participation and meet today's growing demand for cultural content. This approach to culture is not only sustainable over time, but also lays the foundations for future innovations. Innovative technologies towards cultural promotion break new grounds to the expanded fruition of heritage. This work is intended to encourage interests, synergies, innovations, and collaborations in the academic community that contribute to strengthen the current techniques for the digital preservation of Cultural Heritage (Fig. 113).

ACKNOWLEDGEMENTS

Undertaking this interdisciplinary investigation has been both a great privilege and a great challenge, and, certainly, it would not have been possible without the support and contribution of several people and international institutions.

I would foremost like to thank my tutor, Salvatore Barba, for all the opportunities and reliability placed on me. I feel extremely grateful for his encouragement and great supporting since my arrival in Italy almost seven years ago until now. It has been really stimulating to work with him during these years.

I would also like to thank my colleagues and friends at Laboratorio Modelli of the University of Salerno for their support and for creating a pleasant and comfortable atmosphere during the last three years. Special thanks to Emanuela De Feo for her appreciated contribution during the architectural interpretation, to Marco Limongiello for his indispensable training and technical guidance, especially in the photogrammetric phase, to Andrea di Filippo for his helpful comments and collaboration during the survey campaigns, and to Anna Sanseverino for her invaluable help and support during the whole process, especially in the last phase of texturing. Thanks to the whole team of the Lab for sharing with me the joys and successes of these last years.

I would like to thank the direction of Villa Rufolo, on behalf of Secondo Amalfitano, for motivating us and opening the doors of one of the most fascinating places in southern Italy. Thanks to the whole team for the support and valuable contribution.

Special thanks to my co-tutor, Mona Hess, for giving me the opportunity to explore innovative technologies in the field of cultural heritage, for her guidance, enthusiasm, and willingness to work on many projects together and, above all, for becoming in a very short time, a friend.

I would also like to thank my colleagues in the Centre for Heritage Conservation Studies and Technologies at the University of Bamberg in Germany, with whom I shared the last months of my doctorate, where, in spite of the difficult situation we all were going through, I was able to find in them good company and good friendships.

Thanks to the Cisterscapes team for motivating us to work in the wonderful gardens of the Cistercian order. Looking forward to continuing and strengthening the collaboration in the future.

I am extremely grateful to Jacques Laubscher, for his constant words of support and encouragement and also for being part of this journey from the very beginning.

Thanks to the team of the Department of Architecture and Industrial Design of the Tshwane University of Technology in South Africa, especially to Mostert van Schoor, Emmanuel Mbongiseni and Marinda Bolt, for their contribution in our collaboration project. Thanks to Roberto and Victoria Ferraris, without them this collaboration would not have been possible.

Thanks to the Universidad Nacional de Córdoba in Argentina. It was there, where this dream began.

But, more than anything, I have clear that none of this would have been possible without the love and support of my family and friends. Thank you for always being there.

Salerno, March 31st 2021

ACRONYMS

AEC - Architecture, Engineering, and Construction
AR - Augmented Reality
BIM - Building Information Modeling
CAD - Computer Aided Drawing
CH - Cultural Heritage
CDE - Common Data Environment
CRP - Close Range Photogrammetry
DEM - Digital Elevation Model
FOV - Field of View
GCP - Ground Control Point
GIS - Geographic Information System
GNSS - Global Navigation Satellite System
GPR - Ground Penetrating Radar
GPS - Global Positioning System
GPU - Graphic Processing Unit
GSD - Ground Sample Distance
HBIM - Historic Building Information Modeling
ICP - Iterative Closest Point
ICT - Information and Communication Technology
IFC - Industry Foundation Class
IMU - Inertial Measurement Unit
ISO - International Organization for Standardization
IR - Infrared
LIDAR - Light Detection and Ranging
LOA - Level of Accuracy
LOD - Level of Development
LOG - Level of Geometry
LOI - Level of Information
MLS - Mobile Laser Scanning
MMS - Mobile Mapping System
NIR - Near-Infrared
NRTK - Network Real Time Kinematic
SLAM - Simultaneous Localization and Mapping
SFM - Structure from Motion
TLS - Terrestrial Laser Scanning
TST -Total Station Theodolite
TOF - Time of Flight
UAV - Unmanned Vehicle System
VR - Virtual Reality
WHS - World Heritage Site

LIST OF FIGURES

LIST OF VIDEOS

9. BIBLIOGRAPHY

Abbate, E., Invernizzi, S., & Spanò, A. (2020). HBIM parametric modelling from clouds to perform structural analyses based on finite elements: A case study on a parabolic concrete vault. *Applied Geomatics*. https://doi.org/10.1007/s12518-020-00341-4

Amalfitano, S., Barba, S., De Feo, E., Civale, E., Fernandez, L., & Ferreyra, C. (2019). *Villa Rufolo: Una scoperta che dura da mille anni.* Avagliano.

Angulo-Fornos, R., & Castellano-Román, M. (2020). HBIM as Support of Preventive Conservation Actions in Heritage Architecture. Experience of the Renaissance Quadrant Façade of the Cathedral of Seville. *Applied Sciences*, *10*(7), 2428.

Banfi, F. (2019). THE INTEGRATION OF A SCAN-TO-HBIM PROCESS IN BIM APPLICATION: THE DEVELOPMENT OF AN ADD-IN TO GUIDE USERS IN AUTODESK REVIT. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W11*, 141-148. https://doi.org/10.5194/isprs-archives-XLII-2-W11-141-2019

Barazzetti, L., Banfi, F., Brumana, R., Oreni, D., Previtali, M., & Roncoroni, F. (2015). HBIM AND AUGMENTED INFORMATION: TOWARDS A WIDER USER COMMUNITY OF IMAGE AND RANGE-BASED RECONSTRUCTIONS. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5/W7*.

Barba, S., Barbarella, M., Di Benedetto, A., Fiani, M., Gujski, L., & Limongiello, M. (2019). Accuracy Assessment of 3D Photogrammetric Models from an Unmanned Aerial Vehicle. *Drones*, *3*(4), 79. https://doi.org/10.3390/drones3040079

Barba, S., di Filippo, A., Limongiello, M., & Ferreyra, C. (2020). A pipeline for the integration of 3D data on aerophotogrammetric frameworks. The case study of Villa Rufolo. En *D-SITE, Drones—Systems of Information on culTural hEritage. For a spatial and social investigation* (pp. 33-39). Pavia University Press.

Borrmann, A., Konig, M., Koch, C., & Beetz, J. (2018). *Building Information Modeling – Why? What? How?*

Brumana, R., Della Torre, S., Oreni, D., Previtali, M., Cantini, L., Barazzetti, L., Franchi, A., & Banfi, F. (2017). HBIM CHALLENGE AMONG THE PARADIGM OF COMPLEXITY, TOOLS AND PRESERVATION: THE BASILICA DI COLLEMAGGIO 8 YEARS AFTER THE EARTHQUAKE (L'AQUILA). *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W5*, 97-104. https://doi.org/10.5194/isprs-archives-XLII-2-W5-97-2017

Brumana, Raffaella, Georgopoulos, A., Oreni, D., Raimondi, A., & Bregianni, A. (2013). HBIM for Documentation, Dissemination and Management of Built Heritage. The Case Study of St. Maria in Scaria d'Intelvi. *International Journal of Heritage in the Digital Era*, *2*(3), 433-451. https://doi.org/10.1260/2047-4970.2.3.433

Bruno, N., & Roncella, R. (2019). HBIM for Conservation: A New Proposal for Information Modeling. *Remote Sensing*, *11*(15), 1751. https://doi.org/10.3390/rs11151751

Cabrera Revuelta, E., Chávez, M.-J., Barrera Vera, J. A., Fernández Rodríguez, Y., & Caballero Sánchez, M. (2021). Optimization of laser scanner positioning networks for architectural surveys through the design of genetic algorithms. *Measurement*, *174*, 108898. https://doi.org/10.1016/j.measurement.2020.108898

Camera, M. (1836). *Istoria delle città e costiera di Amalfi*.

Chiabrando, F., Lo Turco, M., & Rinaudo, F. (2017). MODELING THE DECAY IN AN HBIM STARTING FROM 3D POINT CLOUDS. A FOLLOWED APPROACH FOR CULTURAL HERITAGE KNOWLEDGE. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W5*, 605-612. https://doi.org/10.5194/isprs-archives-XLII-2-W5-605-2017

Conti, A., Fiorini, L., Massaro, R., Santoni, C., & Tucci, G. (2020). HBIM for the preservation of a historic infrastructure: The Carlo III bridge of the Carolino Aqueduct. *Applied Geomatics*. https://doi.org/10.1007/s12518-020-00335-2

Delius, P., Maggs, T., & Schoeman, A. (2015). *Forgotten World: The Stone Walled Settlements of the Mpumalanga Escarpment*. Wits University Press.

Dore, C., & Murphy, M. (2017). CURRENT STATE OF THE ART HISTORIC BUILDING INFORMATION MODELLING. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W5*, 185-192. https://doi.org/10.5194/isprs-archives-XLII-2-W5-185-2017

Durrant-Whyte, H., & Bailey, T. (2006). Simultaneous localization and mapping: Part I. *IEEE Robotics & Automation Magazine*, *13*(2), 99-110. https://doi.org/10.1109/MRA.2006.1638022

Fan, Y., Feng, Z., Shen, C., Khan, T. U., Mannan, A., Gao, X., Chen, P., & Saeed, S. (2020). A trunk-based SLAM backend for smartphones with online SLAM in large-scale forest inventories. *ISPRS Journal of Photogrammetry and Remote Sensing*, *162*, 41-49. https://doi.org/10.1016/j.isprsjprs.2020.02.006

Fassi, F., Mandelli, A., Teruggi, S., Rechichi, F., Fiorillo, F., & Achille, C. (2016). VR for Cultural Heritage. En L. T. De Paolis & A. Mongelli (Eds.), *Augmented Reality, Virtual Reality, and Computer Graphics* (Vol. 9769, pp. 139-157). Springer International Publishing. https://doi.org/10.1007/978-3-319-40651-0_12

Ferreyra, C., Limongiello, M., di Filippo, A., Barba, S., Van Schoor, M., Laubscher, J., & Nkambule, E. (2020). “Documentation and enhancement of the cultural landscape of South Africa”. En *D-SITE, Drones—Systems of Information on culTural hEritage. For a spatial and social investigation* (pp. 33-39). Pavia University Press.

Ferreyra, C., Sanseverino, A., & di Filippo, A. (2021). Image-based elaborations to improve the hbim level of development. *3Dmodeling&BIM, La Sapienza, Roma*.

Garagnani, S., & Manferdini, A. M. (2013). *PARAMETRIC ACCURACY: BUILDING INFORMATION MODELING PROCESS APPLIED TO THE CULTURAL HERITAGE PRESERVATION*. 6.

Gargano, G. (1997). *Scala medievale, insediamenti, società, istituzioni, forme urbane* (Centro di Cultura e Storia Amalfitana).

GeoSLAM Ltd. (2019). *ZEB-HORIZON User Manual v1.2*.

GeoSLAM Ltd. (2020). *Hub 6 User Manual*.

Girelli, V. A., Borgatti, L., Dellapasqua, M., Mandanici, E., Spreafico, M. C., Tini, M. A., & Bitelli, G. (2017). INTEGRATION OF GEOMATICS TECHNIQUES FOR DIGITIZINGHIGHLY RELEVANT GEOLOGICAL AND CULTURAL HERITAGE SITES:THE CASE OF SAN LEO (ITALY). *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W5*, 281-286. https://doi.org/10.5194/isprs-archives-XLII-2-W5-281-2017

Gollob, C., Ritter, T., & Nothdurft, A. (2020). Forest Inventory with Long Range and High-Speed Personal Laser Scanning (PLS) and Simultaneous Localization and Mapping (SLAM) Technology. *Remote Sensing*, *12*(9), 1509. https://doi.org/10.3390/rs12091509

Grayburn, J., Lischer-Katz, Z., Golubiewski-Davis, K., Ikeshoji-Orlati, V., & Council on Library and Information Resources. (2019). *3D/VR in the academic library: Emerging practices and trends*. https://www.clir.org/wp-content/uploads/sites/6/2019/02/Pub-176.pdf

Grilli, E., & Remondino, F. (2019). Classification of 3D Digital Heritage. *Remote Sensing*, *11*(7), 847. https://doi.org/10.3390/rs11070847

Guidazzoli, A., Liguori, M. C., Imboden, S., Luca, D. D., Bellavia, G., & Verri, L. (2016). *Ati the Etruscan: A transmedia CG character for educational storytelling*. 95.

Guidi, G., & Frischer, B. D. (2020). 3D Digitization of Cultural Heritage. En Y. Liu, N. Pears, P. L. Rosin, & P. Huber (Eds.), *3D Imaging, Analysis and Applications* (pp. 631-697). Springer International Publishing. https://doi.org/10.1007/978-3-030-44070-1_13

Gültekin, N. T., & Özbek Çetin, T. N. N. (2020). Management of Sustainable Tourism and Cultural Heritage for the Ancient Hittite Road. En İ. O. Coşkun, A. Lew, N. Othman, G. Yüksek, & S. G. Aktaş (Eds.), *Heritage Tourism Beyond Borders and Civilizations* (pp. 255-266). Springer Singapore. https://doi.org/10.1007/978-981-15-5370-7_18

Hans Bauer. (2012). *Der Ebracher Hof zu Mainstockheim*.

Hess, M., Schlieder, C., Troi, A., Huth, O., Jagfeld, M., Hindmarch, J., & Henrich, A. (2019). Digital Technologies in Heritage Conservation. Methods of Teaching and Learning This M.Sc. Degree, Unique in Germany. *Advances in Intelligent Systems and Computing*, *919*(Springer, Cham.). https://doi.org/10.1007/978-3-030-12240-9_7

Historic England. (2019). *BIM for Heritage Developing the Asset Information Model*. 64.

Khalil, A., & Stravoravdis, S. (2019). *H-BIM AND THE DOMAINS OF DATA INVESTIGATIONS OF HERITAGE BUILDINGS CURRENT STATE OF THE ART*.

Kosmas, P., Galanakis, G., Constantinou, V., Drossis, G., Christofi, M., Klironomos, I., Zaphiris, P., Antona, M., & Stephanidis, C. (2020). Enhancing accessibility in cultural heritage environments: Considerations for social computing. *Universal Access in the Information Society*, *19*(2), 471-482. https://doi.org/10.1007/s10209-019-00651-4

Kraus, K., Harley, I., & Kyle, S. (2007). *Photogrammetry Geometry from Images and Laser Scans* (De Gruyter).

Laubscher, J., Ferreyra, C., & Sanseverino, A. (2019). SSIMM: Italy-South Africa joint Research Project. The architectural response. *Symposium of Representation Scientific Area for the development of multidisciplinary International programs. Matera, Italia*.

Liang, X., Kukko, A., Kaartinen, H., Hyyppä, J., Yu, X., Jaakkola, A., & Wang, Y. (2014). *Possibilities of a Personal Laser Scanning System for Forest Mapping and Ecosystem Services*. 21.

Limongiello, M., Ronchi, D., & Albano, V. (2020). *BLK2GO for DTM generation in highly vegetated area for detecting and documenting archaeological earthwork anomalies*. 6.

Liu, Y., Pears, N., Rosin, P. L., & Huber, P. (Eds.). (2020). *3D Imaging, Analysis and Applications*. Springer International Publishing. https://doi.org/10.1007/978-3-030-44070-1

Lo Turco, M., Mattone, M., & Rinaudo, F. (2017). METRIC SURVEY AND BIM TECHNOLOGIES TO RECORD DECAY CONDITIONS. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-5/W1*, 261-268. https://doi.org/10.5194/isprs-archives-XLII-5-W1-261-2017

Loulanski, T., & Loulanski, V. (2011). The sustainable integration of cultural heritage and tourism: A meta-study. *Journal of Sustainable Tourism*, *19*(7), 837-862. https://doi.org/10.1080/09669582.2011.553286

Luigini, A., & Basso, A. (2021). Heritage Education for Primary Age Through an Immersive Serious Game. En C. Bolognesi & D. Villa (Eds.), *From Building Information Modelling to Mixed Reality* (pp. 157-174). Springer International Publishing. https://doi.org/10.1007/978-3-030-49278-6_10

Matrone, F., Lingua, A., Pierdicca, R., Malinverni, E., Paolanti, M., Grilli, E., Remondino, F., Murtiyoso, A., & Landes, T. (2020). A benchmark for large-scale heritage point cloud semantic segmentation. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*. https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-1419-2020

Murphy, M., Corns, A., Cahill, J., Eliashvili, K., Chenau, A., Pybus, C., Shaw, R., Devlin, G., Deevy, A., & Truong-Hong, L. (2017). DEVELOPING HISTORIC BUILDING INFORMATION MODELLING GUIDELINES AND PROCEDURES FOR ARCHITECTURAL HERITAGE IN IRELAND. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W5*, 539-546. https://doi.org/10.5194/isprs-archives-XLII-2-W5-539-2017

Murphy, Maurice, McGovern, E., & Pavia, S. (2009). Historic building information modelling (HBIM). *Structural Survey*, *27*(4), 311-327. https://doi.org/10.1108/02630800910985108

Ocampo, R., Ferreyra, C., & Barba, S. (2019). Estimación de los errores y georreferenciación de un levantamiento aereofotogramétrico de un sitio arqueológico en Salta, Argentina. *IX Convención de Agrimensura. La Habana, Cuba.* http://hdl.handle.net/11386/4729522

Osello, A., Lucibello, G., & Morgagni, F. (2018). HBIM and Virtual Tools: A New Chance to Preserve Architectural Heritage. *Buildings*, *8*(1), 12. https://doi.org/10.3390/buildings8010012

Papagiannakis, G., Geronikolakis, E., Pateraki, M., Tsioumas, M., Sylaiou, S., Liarokapis, F., Dimitropoulos, K., Grammalidis, N., Margetis, G., Drossis, G., Vassiliadi, M., Stephanidis, C., & Magnenat-Thalmann, N. (2018). *Mixed Reality Gamified Presence and Storytelling for Virtual Museums*.

Parisi, P., Lo Turco, M., & Giovannini, E. C. (2019). THE VALUE OF KNOWLEDGE THROUGH H-BIM MODELS: HISTORIC DOCUMENTATION WITH A SEMANTIC APPROACH. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W9*, 581-588. https://doi.org/10.5194/isprs-archives-XLII-2-W9-581-2019

Piniotis, G., Soile, S., Bourexis, F., Tsakiri, M., & Ioannidis, C. (2020). *EXPERIMENTAL ASSESSMENT OF 3D NARROW SPACE MAPPING TECHNOLOGIES*.

Previtali, M., & Banfi, F. (2018). Towards the Definition of Workflows for Automation in HBIM Generation. En M. Ioannides, E. Fink, R. Brumana, P. Patias, A. Doulamis, J. Martins, & M. Wallace (Eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection* (Vol. 11196, pp. 52-63). Springer International Publishing. https://doi.org/10.1007/978-3-030-01762-0_5

Previtali, M., Brumana, R., & Banfi, F. (2020). Existing infrastructure cost effective informative modelling with multisource sensed data: TLS, MMS and photogrammetry. *Applied Geomatics*. https://doi.org/10.1007/s12518-020-00326-3

Rahaman, H., Champion, E., & Bekele, M. (2019). From photo to 3D to mixed reality: A complete workflow for cultural heritage visualisation and experience. *Digital Applications in Archaeology and Cultural Heritage*, *13*, e00102. https://doi.org/10.1016/j.daach.2019.e00102

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*.

Salvador García, E., García-Valldecabres, J., & Viñals Blasco, M. J. (2018). The use of HBIM models as a tool for dissemination and public use management of historical architecture: A review. *International Journal of Sustainable Development and Planning*, *13*(01), 96-107. https://doi.org/10.2495/SDP-V13-N1-96-107

Sammartano, G., & Spanò, A. (2018). Point clouds by SLAM-based mobile mapping systems: Accuracy and geometric content validation in multisensor survey and stand-alone acquisition. *Applied Geomatics*, *10*(4), 317-339. https://doi.org/10.1007/s12518-018-0221-7

Sánchez Rivera, J. I., Barba, S., Morena, S., & Merino Gómez, E. (2017). The technologies of architectural survey: A new comparison based on the Tower of Sotillo de la Ribera, Burgos. *Putting Tradition into Practice: Heritage, Place and Design Cham Spriger*. https://doi.org/978-3-319-57937-5_50

Scianna, A., Gristina, S., & Paliaga, S. (2014). Experimental BIM Applications in Archaeology: A Work-Flow. En M. Ioannides, N. Magnenat-Thalmann, E. Fink, R. Žarnić, A.-Y. Yen, & E. Quak (Eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection* (Vol. 8740, pp. 490-498). Springer International Publishing. https://doi.org/10.1007/978-3-319-13695-0_48

Shehata, M., & Rodrigues, F. (Eds.). (2019). *Project Management and BIM for Sustainable Modern Cities: Proceedings of the 2nd GeoMEast International Congress and Exhibition on Sustainable Civil Infrastructures, Egypt 2018 - The Official International Congress of the Soil-Structure Interaction Group in Egypt (SSIGE)* (1st ed. 2019). Springer International Publishing : Imprint: Springer. https://doi.org/10.1007/978-3-030-01905-1

Statham, N. (2019). Scientific rigour of online platforms for 3D visualization of heritage. *Virtual Archaeology Review*, *10*(20), 1. https://doi.org/10.4995/var.2019.9715

Stober, D., Žarnić, R., Penava, D., Podmanicki, M. T., & Virgej-Đurašević, R. (2018). Application of HBIM as a Research Tool for Historical Building Assessment. *Civil Engineering Journal*, *4*(7), 10.

Stylianidis, E. (2020). *Photogrammetric Survey for the Recording and Documentation of Historic Buildings*. Springer International Publishing. https://doi.org/10.1007/978-3-030-47310-5

Stylianidis, E., & Remondino, F. (2016). *3D Recording, Documentation and Management of Cultural Heritage*. Whittles Publishing.

Tommasi, C., Achille, C., Fanzini, D., & Fassi, F. (2020). Advanced Digital Technologies for the Conservation and Valorisation of the UNESCO Sacri Monti. En B. Daniotti, M. Gianinetto, & S. Della Torre (Eds.), *Digital Transformation of the Design, Construction and Management Processes of the Built Environment* (pp. 379-389). Springer International Publishing. https://doi.org/10.1007/978-3-030-33570-0_34

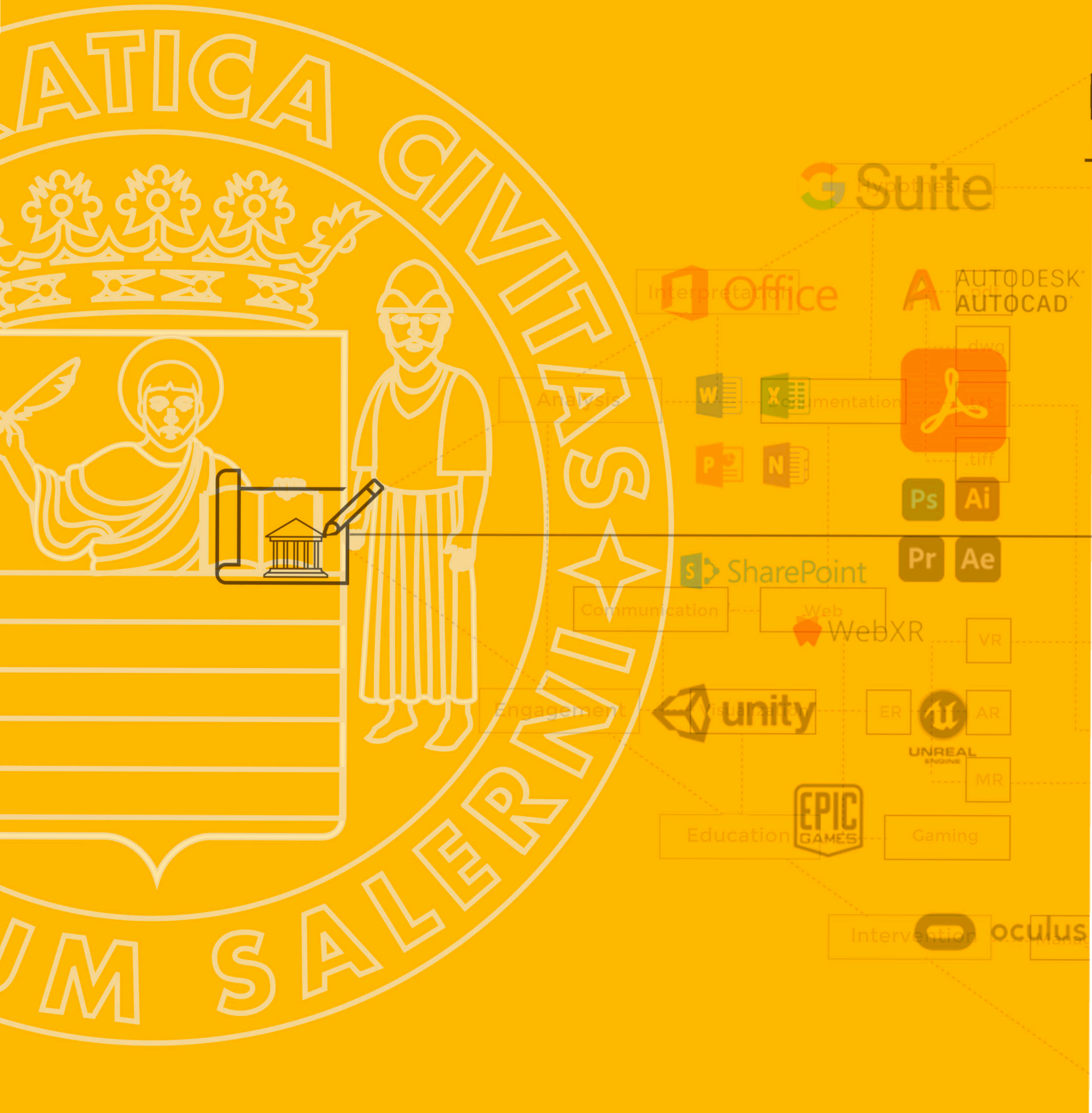
Torresani, A., & Remondino, F. (2019). VIDEOGRAMMETRY VS PHOTOGRAMMETRY FOR HERITAGE 3D RECONSTRUCTION. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W15*, 1157-1162. https://doi.org/10.5194/isprs-archives-XLII-2-W15-1157-2019

Trillo, C., & Petti, L. (2016). A Novel Paradigm to Achieve Sustainable Regeneration in Historical Centres with Cultural Heritage. *Procedia - Social and Behavioral Sciences*, *223*, 693-697. https://doi.org/10.1016/j.sbspro.2016.05.243

Walters, L. C. (2020). *Using Laser Scans and 'Life History' to Remember Heritage in Virtual Environments*. 13.

Wujanz, D., Schaller, S., Gielsdorf, F., & Gründig, L. (2018). *PLANE-BASED REGISTRATION OF SEVERAL THOUSAND LASER SCANS ON STANDARD HARDWARE*. 6.

Yang, X., Lu, Y.-C., Murtiyoso, A., Koehl, M., & Grussenmeyer, P. (2019). HBIM Modeling from the Surface Mesh and Its Extended Capability of Knowledge Representation. *ISPRS International Journal of Geo-Information*, *8*(7), 301. https://doi.org/10.3390/ijgi8070301



ATICA CIVITAS
UM SALERNI
Suite
Hypothesis
Office
Interpretation
AUTODESK
AUTOCAD
.pdf
.dwg
.txt
.tiff
Analysis
Documentation
SharePoint
Communication
Web
WebXR
VR
Engagement
unity
Visualization
ER
AR
UNREAL
MR
Education
EPIC GAMES
Gaming
Intervention
oculus