

Meritxell Simó, Adriana Camprubí
and Xavier Costa-Badia (eds.)

Digitalizing the Middle Ages

Deep Mapping, Third Dimension
and Data Mining

PETER LANG

This volume provides a comprehensive overview of the fast-growing panorama that lies at the crossroads between Digital Humanities and Medieval Studies. Digital tools have become essential for research in the Humanities. The new technical landscape multiplies the options for research, knowledge transfer, and dissemination exponentially. In this context, *Digitalizing the Middle Ages* seeks to highlight the need for a debate on the opportunities but also the risks and challenges posed by the application of Digital Humanities to the study of the medieval world. It brings together cutting-edge technologies and long-established traditions resulting in a true kaleidoscopic perspective which enables the debate on issues that cannot be addressed without innovative holistic methodological approaches. In this sense, the publication will be articulated around the main areas in which Digital Humanities intervene in medieval studies such as Deep Mapping, Third Dimension, and Data Mining.

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Digitalizing the Architectural Heritage for the Study, Dissemination and Preservation of the Franciscan Observant Landscapes

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4.1 Introduction¹

The digital documentation of Architectural Heritage is a rapidly evolving field that involves using state-of-the-art digital technologies to acquire, analyze, preserve, and share morphological, metric, and materic information about investigated buildings and historical monuments. This type of documentation constitutes a fundamental step toward better opportunities for the conservation and enhancement of Architectural Heritage, making the information and research developed in relation to these topics more accessible to researchers and the public.

The digitalization of Architectural Heritage can also be aimed at creating mobile apps, virtual guides, online platforms, and other digital tools that can offer detailed information, high-resolution images, videos, and other multimedia content about monuments, works of art, and places of cultural interest along the Cultural Routes (Gonizzi, Remondino et al. 2014; Letellier and Eppich 2011; Remondino and Campana 2014). The methodologies adopted

¹ This book chapter is a significant outcome of the following projects: F-ATLAS. Franciscan Landscapes: Observance between Italy, Portugal, and Spain (JPI Cultural Heritage—Horizon 2020 program, grant agreement 6995237, PCI2020-112005—URL: <https://www.f-atlas.eu/>) and FREILAS. Women in Military and Hospitaller Orders in the Crown of Aragon (twelfth–sixteenth c.) (funded by MICIU/AEI/10.13039/501100011033 and FEDER/UE, PID2022-136266NB-I00—URL: <https://www.ub.edu/freilas/>).

aim to overcome the static concept of documentation for conservation, moving toward dynamic protection systems that take into account both tangible aspects and those related to intangible cultural heritage (UNESCO 2003). These aspects are particularly important in territories as rich in historical evidence and stratifications as Europe and the Mediterranean world, where today policies of safeguarding and preserving the archaeological and architectural heritage, as evidence of the oldest cultural phases, assume extreme importance. The relevance to the archaeological traces of ancient times and structures of medieval ages, to which most urban systems and territorial arrangements date back, has imposed very important cultural policies related to conservation, which are implemented in different countries with different legislative instruments.

The issue of managing historic architectural heritage in Europe requires greater attention: the bodies responsible for the protection and management of heritage follow various strategies that prioritize conservative and protective approaches, traditionally based on the preservation of paper and photographic documentation related to technical operations and projects. Even when more advanced processes are initiated, such as databases and digital documentation projects, the data protection systems implemented for the purpose of conservation and management appear to lack openness toward the possibility of sharing interoperable databases. Further issues arise concerning the actual preservation of digital data, which, not being stored in interoperable and updatable databases, are subject to the phenomena of operating system aging and the natural obsolescence of recording media. These problems are also due to the extraordinary capacity for evolution and updating of software and hardware offered by a continuously evolving market.

Returning to the issues that afflict the heritage itself, it is noted that recently, in addition to the systemic risk of anthropogenic or natural origin to which heritage, and particularly architectural heritage, is constantly subjected, other factors have emerged—especially the effects of climate change and the consequences of war conflicts that, incredibly, still reoccur in Europe and the Mediterranean basin. It is important to highlight that even recent unforeseen events, such as the fire at Notre-Dame in Paris, the constant environmental and seismic risk in the historic centers of numerous areas, particularly in Italy, have brought the topic of heritage at risk back to the forefront of discussion. The war events, such as the conflict between Ukraine

and Russia, have made us realize that even monuments of great value can be targeted by military activities aimed at weakening the resistance of populations, destroying part of the historical memory and the bond between people and territory.

Another great opportunity offered by the Digital Humanities is the creation of Building Digital Networks for Architectural Heritage. For some time, numerous groups of scholars and scientists have been active in this field. An example is the proposal to adopt the safeguarding protocols recommended by the New European Bauhaus (NEB). This proposal concerns the digitalization of cultural heritage through the enhancement of the concept of cultural routes that follow the guidelines of the European directive and can encourage the availability and systematization of digital databases related to heritage. The Cultural Routes are tourist paths that connect various localities in Europe, enhancing the importance and diversity of the cultural heritage that becomes the object of attention and interest. The issue of using digital technologies to create an interactive and engaging experience along these routes is addressed to allow the visitors to discover and better understand the history, traditions, and art of the places visited, encouraging the integration of digital technology with European Cultural Heritage and promoting its enhancement and sustainable enjoyment.

For this purpose, the way in which the characteristics of individual sites and monuments that are the nodal points of the itineraries are presented to the general public, as well as to insiders and researchers, becomes particularly important. Storytelling becomes a very important step in strengthening the attractiveness of the sites variously included in the itineraries. These can come strongly characterized if we can find common themes of interest and thematic approaches that can, in the light of adequate information activity and critical interpretation, strengthen the realization of real networks within which both information related to the history of the site and elements of interest related to contemporary use or tourist or commercial offerings can coexist.

In Europe interest often focuses, as mentioned earlier, on monuments and sites that have prevailing facies related to the Middle Ages and that, because of the many historical and constructive events, present today an interesting characterization in a diachronic sense. This provides an interesting opportunity to enhance storytelling by creating diachronic models capable of functioning as true interactive data archives related to the history and

evolution of the building complex or the urban fabric. Through the study of historical archives and the digitalization and organization of documentary material, it will be possible to refer to these three-dimensional models to improve the aspects of heritage storytelling and make it more accessible to a wider audience. Also, where the opportunity arises, archaeological studies, focusing on the study of material sources and the analysis of elevated masonry, can integrate valuable data for the conservation of historical evidence and contribute with critical readings of artifacts that, bearing witness to historical events, constitute live and effective collections of data, valuable testimonies of the heritage's history and its related territorial contexts. These products can finally be made accessible through the development of virtual experiences and digital applications such as the ones we intend to show later.

4.2 The F-ATLAS Project

In this chapter we present the European project F-ATLAS—Franciscan Landscapes: the Observance between Italy, Portugal and Spain, coordinated by the Department of Architecture of the University of Florence, in partnership with the Institute of Research on Medieval Cultures of the University of Barcelona, the Instituto Universitário de Lisboa, and the Universidade Católica Portuguesa. Based on the objectives outlined earlier, this project aimed to catalog a typology of heritage defined by the ecclesiastical and conventual architecture of the Franciscan order, particularly that of the Observance, which spread throughout Europe from the fourteenth century onward and often took advantage of the recolonization or revitalization of abandoned or failing medieval or even late antique places of worship.

This project focuses on documenting and preserving the Cultural Heritage of Italian, Spanish, and Portuguese Franciscan Observance sites, a crucial aspect of European culture influenced by St. Francis of Assisi. Many of these architectural complexes are now at risk of losing their original purpose and meaning due to the marginality to which such complexes are often relegated. This contribution describes the methodology used in the project, which, by combining traditional and innovative techniques, aims to evaluate the current condition of these sites and to create a comprehensive 'Atlas' for conservation and promotion of this important heritage. F-ATLAS has been interested in the digitization of the architectures of European Observant Franciscanism,

but also in their territorial dimension. The georeferencing of each of these buildings in a unique Atlas WebMap has allowed us to create an interactive tool for knowledge transfer, capable of connecting each building with the territory where it is located, allowing a holistic and multilevel approach to the monastic landscape that it generates. Both the digitization of convents and their territorial connection through the implementation of a geolocated digital catalog constitute the main focus of the present study.

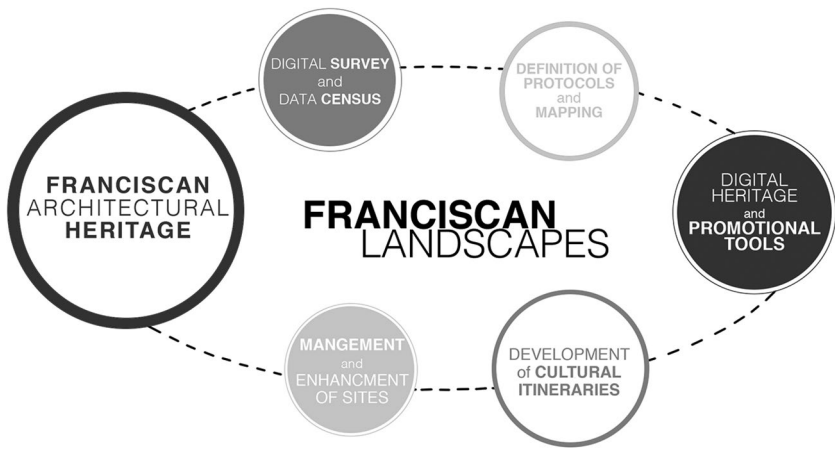


Figure 4.1: Methodological flow of F-ATLAS project.

Starting from a corpus of historical investigations, which formed a significant part of the project focusing on Franciscan Observance Religious Cultural Heritage, the interdisciplinary research delved into the evolution of Franciscan convents, examining their organization over the centuries and their intricate relationship with local territories and cultures, giving us a picture of the historical context in which the Observance movement flourished. Special attention is given to peripheral and abandoned areas, emphasizing their historical and cultural significance. By developing a network of cultural and sustainable tourism, the project seeks to connect and unite scattered cultural assets, raising awareness and passing on traditional values. The collaboration involves European institutions with expertise in remote sensing, historical analysis, and cataloging, contributing to a global understanding of the cultural heritage studied.

One of the highlights of the F-ATLAS project has been the emphasis given on the leveraging cutting-edge technologies for Franciscan's Architectural Heritage analysis and digitization (see Figure 4.1), using the potential of contemporary technologies in the field of digital technologies using drones, 3D laser scanners, digital photogrammetry, augmented reality/virtual reality (AR/VR), Geographic Information Systems (GIS), and 3D printing in documenting religious architectural heritage. These digital tools provided researchers with new ways to collect, analyze, and present architectural data, enabling a deeper understanding of the complex structures and landscapes associated with the Franciscan Observance.

The F-ATLAS project has completed its research through the organization of an international conference that has fostered international collaboration, with scholars that brought their unique perspectives to the discussions, enriching the exploration of Franciscan Observance beyond European borders (Bertocci and Cioli 2024). This global engagement highlighted the universal significance of religious heritage and the need for international cooperation in its preservation.

4.3 Digitalizing the Architectural Heritage

4.3.1 Methodology and Techniques

In order to digitize the architectural heritage of the Franciscan Observance, we have made use of a set of innovative tools. Integrated digital survey methodologies include the use of non-invasive acquisition techniques (remote sensing), such as Terrestrial Laser Scanning (TLS) and Structure-from-Motion (SfM) photogrammetry, both at close range from the ground and using drones (unmanned aerial vehicles—UAVs). Thanks to this approach, it is possible to create a highly descriptive and accurate three-dimensional database of the architectural complexes, from which it is possible to obtain detailed architectural drawings in various scales of representation, such as plans, elevations, sections enriched by the chromatic data of the orthoimages calibrated on the reference point clouds produced by a 3D laser scanner. These documents serve as reliable data for structural monitoring and aid in interpreting the decorative apparatuses and reading the traces of the stratigraphy of the wall structures. This helps to clarify a site's historical, artistic, archaeological, and architectural aspects.

After conducting a field survey with digital tools, it is crucial to carefully handle the data collected in the laboratory, ensuring accurate recording and calibration of information from different instruments. This is essential for building a highly reliable database. The architect must possess specific professional skills to plan and execute field activities and accurately acquire data. This approach is particularly important for architects working in conservation and restoration, as it allows them to effectively use modern technologies to obtain precise knowledge of the subject (Bigongiari 2020).

The field of digital surveying encompasses the analysis and understanding of detected objects, including their physical dimensions, materials, historical context, and intangible characteristics. Surveys can have various objectives, and different tools are available to achieve them. Digital surveys can investigate territorial systems, urban systems, architectural complexes, and artifacts. When designing a digital survey campaign, it's important to consider the following:

- a) The object's characteristics, like accessibility, dimensions, and architectural features.
- b) The purposes of the operation could be technical, scientific, informative, or for dissemination. These purposes could require 2D drawings, 3D models, GIS, virtual, augmented, or mixed reality applications.

The used methodologies are based on two data acquisition methods: range-based and image-based. Data acquisition tools that use range-based technologies obtain information based on distance measurements. These systems are characterized by active sensors that send out a signal for measurement. On the other hand, image-based data acquisition tools gather the necessary information for the survey from images. Image-based instruments use passive sensors, so they don't emit signals. Instead, they interpret image points to take measurements. There are two main types of methodologies mostly applied to architectural surveys: laser-scanner survey, which gathers three-dimensional data for analyzing architectural geometry and dimensions, and photogrammetric Structure-from-Motion (SfM), which constructs 3D models with photo textures for materials analysis and surface conservation assessment. The output of the laser-scanner survey is a high-precision 3D point cloud representing the scanned space. The output of the SfM photogrammetric

survey is a 3D mesh model created from common points in a sequence of photos taken at different angles.

Digital technologies have undergone rapid development in the cultural heritage sector. Hand in hand with the restoration sector's tendency to increasingly involve the skills of pure science sectors, such as physics and chemistry, survey methodologies have also specialized toward structuring increasingly accurate, verifiable, and multi-scale information models. These methodologies are specialized to create accurate, multi-scale information models using techniques such as LIDAR, structured light, and photogrammetry. The choice of instrumentation depends on the survey objectives, the object being surveyed, and the available budget and time.

When documenting a site, it's important to consider factors like accuracy, portability, cost optimization, fast acquisition, and flexibility. Often, surveys require the integration of different technologies and instruments because a single methodology can't encompass all these characteristics. The data produced by different instruments will vary in resolution, quality, and type (i.e., point cloud and mesh). Therefore, correct post-production and data optimization are essential to obtain a model that is as consistent and reliable as possible. Even when using the same instrument, parameter variations or distance from the object can result in inconsistent outcomes. When integrating models, it's necessary to define a level of detail (LOD) and accept some information loss to achieve better readability and consistency.

The methodologies have evolved and become more specialized through the interaction of engineering, archaeology, geomatics, and architecture disciplines. They now cater to a wide range of materials and different needs. For instance, structured light lasers have been developed for detailed surveying. They are primarily used to create precise 3D models of objects, artifacts, and textile materials, as well as in medicine and dentistry.

Currently, the most relevant methodologies in architecture are laser-scanner surveys, which can be mobile or static, and Structure-from-Motion (SfM), including close-range and UAV photogrammetry. These technologies are combined to gather reliable data, both metrically and geometrically, as well as material and color properties. Integrated digital surveys are used in restoration, archaeology, and cultural heritage to create informative 3D models for analytical, technical, and surface mapping purposes, essential for diagnosing surface degradations, wall stratigraphy, and structural issues.

The integrated digital survey supports the construction of models, constituting an accurate, implementable database for developing accessible virtual systems for research and dissemination. In this scenario, one main challenge is optimizing the data for usability while maintaining the appropriate level of detail. While until recently, we proceeded through NURBS or mesh modeling to recreate virtual discretized environments, we now increasingly use colored point cloud models directly, saving the time-consuming 3D modeling processes. This process is made possible by the new models of laser scanners with integrated cameras, which have appeared since the end of the 1990s and provide a highly descriptive model. Some of these scanners produce HDR panoramic images via 360° rotation of the instrument. Unfortunately, however, the RGB values are not in an absolute color space (Munoz-Pandiella, Comino et al. 2022). Consequently, the scans can present significant chromatic differences and, therefore, require specific processes for optimizing the graphic rendering, which still has not been adequately explored. These environmental models can be integrated with detailed mesh models to establish virtual tours with interactive and informative works of art, artifacts and objects (Bent, Pfaff et al. 2022).

4.3.2 Implementation in the F-ATLAS Project

As mentioned earlier, the F-ATLAS project constitutes an excellent example of the experimentation, consolidation, and development of integrated digital survey methodological protocols. The integrated digital survey activities combined traditional and innovative techniques to develop methodologies, protocols, risk assessment tools, and user-friendly interfaces for managing and enhancing cultural heritage. This involved creating a constantly updatable digital database that could be used as a basis for various activities. The environmental component of these settlements and the consistent architectural development in the layout and distribution systems allowed for the application of environmental, architectural, and detailed survey methodologies. This offered a wide range of possibilities and outputs while presenting a challenge regarding data interoperability.

The integrated digital survey campaigns were conducted in the following case studies, which were considered particularly representative of the project due to their architectural and environmental features: Convento del Sacro Speco di San Francesco (Narni, Umbria, Italy); Convento della Porziuncola in

Santa Maria degli Angeli (Assisi, Umbria, Italy); Convento di San Bartolomeo (Foligno (PG), Umbria, Italy); Eremo delle Carceri (Assisi (PG), Umbria, Italy); La Romita di Cesi (Narni (TR), Umbria, Italy); Convento Nossa Senhora da Ínsua (Caminha, Norte, Portugal); Convento Santa Maria de Mosteiró (Valença, Norte, Portugal); Convento Sao Francisco do Monte (Viana do Castelo, Norte, Portugal); Castell-Monestir de Sant Miquel d'Escornalbou (Riudecanyes, Catalonia, Spain); Convento de San Francisco (Chelva, Valencian Community, Spain); Eremo de San Francisco (Chelva, Valencian Community, Spain). The result of this digitization work can be found on the project website (<<https://www.f-atlas.eu/>>), as well as in some publications (Cioli and Lumini 2021; Cottini 2022; Bertocci, Ferrari, and Cioli 2023; Soler, Ferretti, and Cioli 2023; Volzone, Becherini, and Cottini 2023; Soler, Jornet, and Garí 2024).

Planning survey operations require careful consideration to avoid missing data or gathering incorrect information. A preliminary inspection helped identify problems and morphological complexities in different case studies, which allowed for developing a precise strategy for the digital survey campaign. The documentation campaign aimed to create a digital database to support the cognitive study by producing 1:50 scale architectural drawings and orthoimages. These would aid in the analysis of wall stratigraphy and the interpretation of construction phases.

4.3.2.1 Laser-Scanner Survey

LIDAR (laser imaging, detection, and ranging) systems are commonly used in architectural and infrastructural surveying due to their performance characteristics and methods of use. LIDAR systems are divided into two categories: Time of flight, where the measured point coordinates are calculated based on the time elapsed between the emission (outward journey) of the laser signal and its reflection (return); and Phase shift, where the coordinates of the measured point are calculated based on the phase variation undergone by the laser signal between emission (outgoing) and reflection (return). Each scan has its reference system, which coincides with the optical center of the instrument. Establishing a common coordinate system is important, as it aligns the survey scans to register all scans conducted in various locations. Once the laser-scanner survey registration is finished and verified, we obtain the 3D point cloud (see Figures 4.2 and 4.3). The model can be segmented using section planes, and orthographic images can be exported to create 2D and 3D drawings.



Figure 4.2: 3D point cloud of the Santa Catarina da Ínsua convent, Camina, Portugal.

This process requires the creation of a 3D point cloud model with an appropriate level of reliability based on the graphical restitution scale of the outputs. Usually, the contribution of a topographic station in the field is also envisaged, traditionally used to create reference points for verifying the alignment of the laser scanner scans through a mesh of fixed points constituting a topographic polygon. Typically, topographic instrumentation establishes a reference grid to compensate for individual measurements' instrumental error.

The TLS surveys used two different models of laser scanners: a Z+F IMAGER 5016 and a FARO Focus M70, both using phase-shift technology. The Z+F IMAGER 5016 was mainly used for external scans due to its wide range, suitable for acquiring portions of the landscape context. The FARO Focus M70 was used for internal environments, being smaller, more manageable, and lighter, with a smaller range than the Z+F IMAGER 5016. The data obtained from the laser-scanner surveys were imported and processed using specific software such as Leica Cyclone to manage point clouds. The primary process of filtering (i.e., noise reduction in acquired data), cloud-to-cloud registration (a procedure for visual alignment that exploits a series of rigid transformations), certification (i.e., verification of the reliability of the acquired measurements and correction of errors), and processing (i.e., obtaining raw data related to plans, elevations, and sections of the building that will form the basis for technical drawings) of the global point clouds were developed using this software.

The 3D point cloud is the reference to create 2D drawings of plans, sections, elevations, and axonometric views. These drawings are imported into software like Autodesk AutoCAD or Rhinoceros to create accurate technical drawings or NURBS 3D models. The scale of the drawings can range from landscape to detailed scales like 1:50 or 1:20 and can be used to represent distribution schemes and maps of deterioration and surface damage. Creating 3D models is an effective way to visualize the entire building complex in three dimensions and to show its essential volumes, such as construction phases. Orthoimages of the facades can be obtained from the mesh models and rectified images of the wall surfaces. Combined with point cloud data, these images can be used to create 2D representations of plans, elevations, and sections, providing information on the color and texture of the facade surfaces.

The registration involves the creation of an overall point cloud model by roto-translating the individual point clouds to assign a single coordinate system. Each point cloud is a set of points with a relative polar coordinate system arranged with the origin in the scanner head. The roto-translation of the scans makes all the points cloud models undergo a rigid movement, aligning them with the coordinate system of another cloud taken as reference. The process allows the alignment of all the scans in a single general cloud equipped with a single reference system in local polar coordinates. After the preliminary stages of filtering the acquired data, the overall point cloud was

“cleaned,” that is, deprived of imprecisely generated points due to reflections or incongruous elements (i.e., people moving in the scene) or uninteresting elements for the project.

The scans were managed and registered using Leica Cyclone 2020 software. The process involved cloud-to-cloud recording without the need for targets. Visual alignment was used initially, followed by calibration through the “cloud constraint” function. The registration’s reliability was verified by checking the metric error against job-specific reliability specifications and ensuring that the overlap of corresponding surfaces in the point clouds did not exceed tolerances set for a 1:50 scale.² This was confirmed through vertical and horizontal checks on section plans, guaranteeing the reliability of the cloud section wires.³



Figure 4.3: 3D point cloud of the Franciscan Convent of Chelva, Valencia, Spain.

After ensuring the three-dimensional model was reliable, we defined the section plans needed to cut the models to create two-dimensional architectural drawings like plans, elevations, and sections, providing a complete geometric

² Based on the ISO 4463-3:1995 regulation relating to the 1:50 representation scale, specific precision limits are established, with a tolerance of ± 12 mm.

³ The point cloud was divided by planes and, using the slice view, it was possible to examine all intersections between the overall 3D model and the plane. This process allowed us to verify the absence of significant errors, ensuring a high level of precision within 1 cm across the entire architectural complex.

representation of the architectural complex. These views were then exported and integrated into a CAD environment, where they were aligned to the drawing pad using numerical references of spatial coordinates and rotation angles corresponding to those of the model managed in Cyclone.

The architectural drawings were then created in CAD and organized into distinct layers. This subdivision allows a clear distinction, both semantically and graphically, between section lines and the first and second levels of depth and between the representation of objects such as stones and ashlars compared to fixtures and vegetation.

4.3.2.2 SfM Photogrammetry

The photographic campaign plays a crucial role in all documentation activities of the architectural heritage and survey operations. Photographic images contain rich information relating to the subject's appearance and from a metric point of view. Photogrammetry involves acquiring metric data of an object, including shape and position in space, by analyzing a pair of stereometric frames. The Structure-from-Motion method allows you to digitally reproduce a real object by taking photographs while moving around the object. These photos must be arranged continuously and orderly, with at least a 60 percent overlap between each frame. The object can be captured through multiple close-range and low-altitude photography sessions. With the help of specialized software, it's possible to create a three-dimensional model that accurately represents the material characteristics of the surfaces in the photographs. This model can be used in various applications such as creating virtual immersive environments, Digital Twin, or 3D printing.

Photogrammetry is based on the principle that any point on the object being photographed will always be found along the ray that extends from the camera's optical center to infinity. By taking a pair of frames from different positions, we can obtain a stereoscopic vision and appreciate each point's three dimensions. Image-based acquisition tools are divided into aerial photogrammetry, low-altitude photogrammetry (e.g., drone), and close-range photogrammetry. Photogrammetry is divided into two main categories based on the survey purpose: flat or 2D photogrammetry and 3D photogrammetry (see Figures 4.4 and 4.5). Flat photogrammetry aims to reproduce two-dimensional drawings, such as territorial maps or architectural elevations. It involves creating orthoimages by identifying homologous points on the same

plane, through which it is possible to carry out a homographic transformation or rectification. It is necessary to have at least four points in common between the various photographs and have their coordinates detected using a direct, topographic, or laser-scanner survey. In cases where notable points cannot be identified, targets must be used.



Figure 4.4: 3D photogrammetry close-range and by UAV of the Castell-Monestir de Sant Miquel d'Escornalbou, Tarragona, Spain.

In the scope of the European F-ATLAS project, a Structure-from-Motion (SfM) photogrammetric survey was conducted alongside the laser-scanner survey campaign. This was done to produce detailed and textured three-dimensional models and integrate metric-morphological data from the obtained point clouds via TLS. The aim of this approach is to provide detailed information on the appearance and conservation status of the architectural elements of the structure under examination (Forgione, Arrighetti et al. 2022). The goal is to generate textured orthoimages of the exterior walls and interior surfaces, particularly those adorned with decorations or frescoes. Creating orthoimages enabled the development of technical documents for studying wall structures and documenting the materials' conservation status and surfaces.

Two types of cameras were used for the photographic surveys: digital cameras for close-range acquisition and drone cameras for high-altitude acquisition. The digital camera captured photos of the convent complexes,

documenting the context and the most relevant details. These photos helped integrate the cataloging sheets and the operations of the working group. The digital camera was also used for photogrammetric surveying, creating three-dimensional mesh models that were accurately scaled by comparing them with the point cloud and the laser-scanner texture. The drone was used to capture high-altitude photographs, providing views of the portions of the building not visible from the ground, such as the roofs and upper parts of overhanging elements.

The acquired photographic data were subsequently processed using Agisoft Metashape Pro software, a photo-modeling application based on Structure-from-Motion (SfM) processes. This software allows the import of captured images and, through image-matching processes, identifies the homologous points between the shots, determining the position and orientation of each point in space. The initial result of this process is an alignment of the acquired images, displayed as a sparse cloud composed of the calculated points.

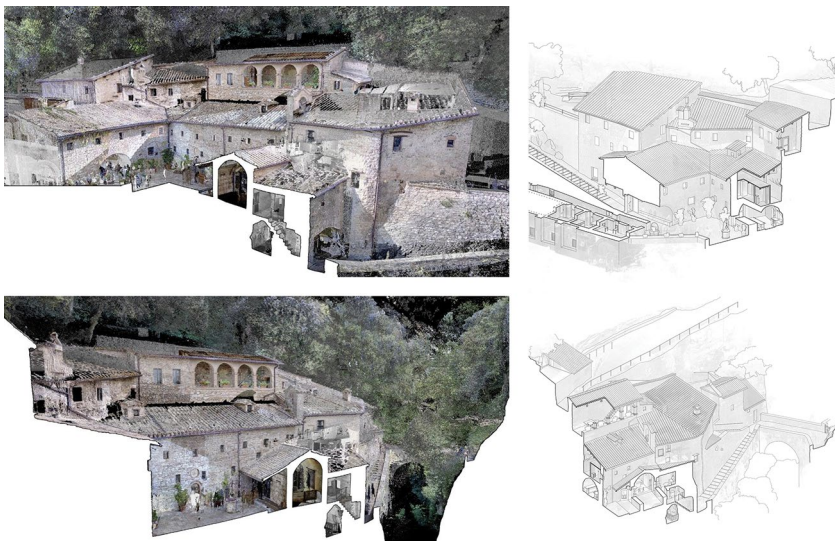


Figure 4.5: 2D drawings of the Eremo delle Carceri, Assisi, Italy.

The process begins with a sparse point cloud, which is then converted into a denser point cloud using specific calculation algorithms. This densified point cloud is then used to create a 3D mesh model through triangulation and

polygonalization. Subsequently, photographic images are projected onto the mesh to generate a photographic texture mapping for the entire 3D model. We can extract orthoimages from this model for further analysis (Ferdiani, Demetrescu et al. 2019). Integrating data from UAV devices and TLS surveys has expanded the possibilities of acquiring comprehensive site information and creating essential graphics like orthoimages for in-depth analysis.

After obtaining textured 3D models from close-range and UAV surveys, we referenced and calibrated them using coordinates from homologous points identified on the point cloud from the laser-scanner survey. This integration process combines information from both surveys to create a reliable 3D model with detailed and accurate documentation of the surfaces.

4.3.2.3 Future Developments

The generated models were crucial in creating 2D vector representations such as plans, elevations, and sections. Orthoimages were exported from the Leica Cyclone software and then imported into AutoCAD. Initially, the models were cut and displayed in an orthogonal view using the slice mode to highlight the section line where the 3D model intersected with the plane. Then, the half-space mode was used to highlight all elements in an orthogonal projection and to ensure proper sizing. The orthoimages obtained were then imported into AutoCAD and georeferenced based on the polar references of the point cloud to reconstruct a complete orthoimage of the work to be represented. After a thorough review process, polishing, and discretization of the point cloud data, wireframe graphics at a 1:50 scale were developed. These documents provided solid metric support for calibrating the photo plans created by exporting the orthoimage from the Agisoft Metashape software.

The set of documents created in both 2D and 3D formats, obtained through careful data analysis and precise organization of the information gathered using the methods described earlier, is a dependable tool for documenting archaeological, artistic, and architectural aspects. It provides valuable support for analyzing the measurements and materials' physical and visual characteristics. As we have seen, remote-sensing technologies and those for cultural heritage documentation allow the creation of highly accurate 3D models that can be used for historical documentation, design, restoration, typological comparison, material and structural monitoring, development of virtual reality applications, the implementation of shared databases of web-based data or GIS, etc. (Remondino 2011).

In past years, the lack of dedicated skills, software and hardware has often failed to exploit the potential of three-dimensional data, often reducing it to 2D documents or simplified 3D models. Many of the analyses that can be done on a 3D point cloud model from a laser-scanner survey, such as the analysis of deformation maps with respect to the axiality of the surfaces, are lost if the model is simplified. Similar problems emerge in scan-to-BIM processes, where the remodeled surfaces lose any deformations necessary to study restoration and consolidation interventions. These procedures work very well in the context of modern or contemporary architecture but present many problems for historic buildings.

Recently, there has been a discussion about using digital twins in cultural heritage. A digital twin is a complete virtual representation of a physical object, with accuracy at both micro and macro levels. This virtual description is created through twinning, which involves synchronizing the virtual state with the physical one. This synchronization occurs reciprocally and at a certain frequency. In the field of architecture, a similar but more established concept is Building Information Modeling (BIM), which aims to provide a single source for all stakeholders involved in a building's production process, allowing them to manage the entire life cycle of the building (Jones, Snider et al. 2020).

One of the main challenges we will encounter is the need to establish international standards for managing and conserving files, removing the responsibility from private companies. Companies that produce equipment and the associated proprietary software increasingly use file formats that different software cannot open. To ensure the future integrity of the data, we will need to re-export all files into the most currently compatible formats (e.g.,. ptx.,. pts.,. e57), with the risk that these formats, too, may become obsolete in the future.

4.4 Digitalizing the Monastic Landscapes

4.4.1 Digital Network of Conventual Buildings

In recent years, interest in the spatial variable has surged within the Humanities and has provided a valuable approach to cultural and historical phenomena. In this context, the study of medieval monasteries and their impact on the territory has become a very promising line of research (Garí, Soler et al. 2014), which aims to understand the relationship of these centers of spirituality with the territory, the economy and the society along the time.

Exploring the relationship of a given monastery with its territorial environment requires making use of the holistic concept of “Landscape” (Antrop and Van Aetvelde 2017; Burnouf 2011; Bolòs 2014), understood as the space of connection of the set of elements that constitute the complexity of the past. From the specific focus of this definition in the field of monastic buildings emerged, some years ago, the conceptualization of “monastic landscape” (Cassidy-Welch 2001; Bond 2004), understood as a way of approaching the relationships that a given monastery establishes with its immediate, nearby or more distant surroundings. According to this definition, the monastery is not an isolated entity, but a node closely connected to the territory where it is located. For this reason, we are interested not only in mapping its position in space, but also in representing through *deep mapping* tools (Bodenhamer, Corrigan, and Trevor 2015) the set of relationships, progressions and connections resulting from its interaction with the surrounding landscape.

The commitment to *spatial turn* has allowed us to think the cultural phenomena in terms of space, and through an interdisciplinary approach (Gámir 2019; Torre 2008). This approach has been enhanced by the multitude of options for data representation and analysis made possible by the digital environment (Presner and Johanson 2009; Rojas Castro 2013). On this basis, a few years ago, a pioneering project was set up: “CLAUSTRA. Atlas de la Espiritualidad Femenina Medieval,” lead by Blanca Garí from the University of Barcelona, which located and cataloged the spaces of female spirituality documented between the twelfth and sixteenth centuries in the kingdoms of the Iberian Peninsula, the Crown of Aragon, and its territories of influence: southern Italy, Sicily and Sardinia (<<https://www.ub.edu/claustra/spa/Monestirs/atles>>).

Following the methodological framework of this earlier experience, but using more advanced tools adapted to current technological developments, we have created the Catalog of Franciscan Observant Monasteries (<<https://www.f-atlas.eu/case-studies-map>>). This interactive digital platform, accessible from the project’s website under the name F-ATLAS WebMap, has allowed us to take a significant step further in the transdisciplinary conception of data registration methods and in the development of digital tools for cartographic representation and visualization. These tools have been adapted to a collaborative environment and provide free access to information, in line with the principles of open science and knowledge transfer. The objective was to geo-reference and catalog all the monasteries of the Franciscan

Observance in Spain, Portugal and Umbria in order to create a true digital network of conventual buildings. This network is valuable not only from a scientific perspective, but also in terms of dissemination and knowledge transfer, due to its potential to connect with cultural routes and promote the cultural heritage of the territory.

4.4.2 Methodology and Techniques

In order to develop an Atlas and Catalog of the monasteries of the Franciscan Observance, capable of displaying on digital maps all the information generated by the project (including the 3D models resulting from the process of digitalizing the architectural heritage), it was necessary to create a database system capable of recording data from architecture, archaeology and historical texts. On the other hand, we have also made use of GIS, both for the elaboration of synchronous and sequential digital cartographies, and for the application of complex analytical algorithms in the study of the data.

Throughout this methodological system, georeferencing has always played a fundamental role, as it has allowed us to homogenize the diversity of data from sources of different materiality (textual, archaeological, architectural, territorial) and represent them in the same digital cartographic base, transforming the resulting cartographies into true sources of knowledge. On this basis, each monastery constitutes a node connected to the information contained in the database and forms part of a network of georeferenced places on the map and of great cultural and heritage interest.

4.4.2.1 Relational and Multi-User Database

In order to cartographically represent all the monasteries studied, the F-ATLAS project required a georeferenced database that would facilitate simultaneous collaboration among its researchers. It was essential to develop a structured and coherent system for information recording, capable of integrating data of diverse origin and materiality (texts, numbers, hyperlinks, images) in the same file (Soler, Ferrer, Cioli et al. 2024: 153–156). After a thorough preliminary assessment of the research requirements, we began the design and implementation of a relational, multi-user, and multi-platform database system, which uses the open-source software MySQL as a storage engine, together with an interface based on *Adminer*, which allows easy and secure data entry from any browser.

The F-ATLAS relational database is structured around a main datatable containing the descriptive fields of each monastery, together with several auxiliary tables that define in advance the datasets of interest (Ferrer 2024: 488). The database record contains the following information fields: name of the monastery; name of the region (NUTS-2 system); georeferencing coordinates (EPSG system: 4326); precision of the location (“Specific,” for exact coordinates; “Generic,” when exact coordinates are unavailable but the convent can be linked to its current or historical region, or “None,” when the monastery has disappeared); name of the monastic order(s) that dwelled in each building and its historical chronology; state of conservation of the monument (“Existing,” “Disappeared” or “In ruins”); protection status of the building (“Local,” “National,” “UNESCO,” “Others” or “None”); bibliography or webgraphy; and images (photographs, planimetries, 3D virtualizations), with their respective informative references.

4.4.2.2 Geospatial Data Server and Map Viewer

To visualize all the information recorded in the project’s data system into a single digital cartographic interface, we developed and implemented an interactive geospatial data server linked with a map viewer (Soler, Ferrer, Cioli et al. 2024: 154). This WebMap is structured on a layer of points connected to the database, which provides both the geographical location data of each monastery and all the descriptive information, as well as various images (photographs, plans, 3D visualizations) illustrating each site. This diversity of information is associated with its corresponding point on the map, and can be accessed both for individual monastery characterization and for generating thematic cartographies based on the filters applied during searches.

The WebMap of the project makes use a GIS-based georeferenced representation system, through the open-source *QGIS* software (Ferrer 2024: 489). Additionally, it incorporates web mapping principles to create an interactive cartographic interface, enhancing the visualization of geospatial data on the project’s website (<<https://www.f-atlas.eu/case-studies-map>>). The design of the F-ATLAS WebMap represents an innovative approach, combining the strengths of georeferenced databases with the spatial analysis capabilities of GIS into a single digital tool. By employing a geospatial viewer, our proposal aims to go a step further in the use of georeferencing systems, overcoming the individual nature of traditional GIS work and offering the opportunity

to share with other researchers and the general public all the georeferenced information. This process has been implemented using *Leaflet*, an open-source library specialized in interactive map creation, which has streamlined the integration of our WebMap.

4.4.3 Social Transfer and Dissemination Tools

4.4.3.1 F-ATLAS WebMap

The georeferenced catalog of the Franciscan Observant Monasteries (F-ATLAS WebMap) is one of the key achievements of the project. Not only does it stand out as an innovative contribution to the field of Digital Humanities, but it is also significant for its ability to integrate the dispersed set of monasteries of the European Franciscan Observance (in Spain, Portugal, and Italy) in a single digital tool (Soler, Ferrer, Cioli et al. 2024: 149–161). This interactive map allows users to access all the information developed and cataloged by the project.

From its inception, the catalog was also designed with a strong interdisciplinary focus, placing the historical data of each monastery (name, chronology, changes of order) on the same level of visualization and search as the heritage characterization data (state of conservation and protection regime of the buildings). This integration makes our catalog and WebMap platform a digital resource of significant thematic and methodological value, with great potential applications in other fields and contexts. Additionally, the use of 3D virtualization methodologies for conventual buildings, along with the diagnosis of their conservation status, can be of particular interest to those responsible for the preservation and maintenance of this valuable heritage (Bertocci and Cioli 2024).

The F-ATLAS Catalog contains nearly 1,000 convents of the Franciscan Observance, all registered, georeferenced, and represented on the cartographic bases of our map viewer (see Figure 4.6). This information is linked to each of the georeferenced points represented on the different layers of our WebMap, which offers various visualizations and filters capable of creating thematic maps at different scales. In order to better adapt to the different types of users and promote the dissemination of results, our WebMap incorporates two different visualization modes. The first mode is aimed at those interested in taking a quick look at the information as a whole. Here, the viewer displays the data through a simple interface, using colored clusters that automatically group the monasteries according to the

scale of the map and the size of the user's screen (<<https://www.f-atlas.eu/case-studies-map>>). The second visualization mode, in contrast, is designed for a more specialized audience, interested in generating their own thematic cartographies using the full dataset stored in the database (<<https://www.f-atlas.eu/extended-filters>>). This advanced version has an interactive chronological bar, enabling users to visualize the evolution of the Observance along the time. It also allows the application of various filters to view the observant monasteries according to their state of conservation, their protection status, or geographic region.



Figure 4.6: Screenshots of the F-ATLAS Catalog and WebMap.

In both the basic and advanced formats, users can select the visualization base (satellite or cartographic mode), adjust the zoom level, access the complete file of each monastery and carry out specific searches based on the name of the monastery, a specific region or their current location. Additionally, users can utilize the “zoom in” and “zoom out” tools to navigate closer to or farther from the visualized monasteries as needed.

4.4.3.2 F-ATLAS Virtual Museum

The Virtual Museum of F-ATLAS was created with the goal of enhancing the dissemination and transfer potential of the information contained in our monastery catalog. Aimed at creating a dissemination tool accessible from smartphones, tablets or any other mobile devices, and capable of connecting the information generated by the project with the strategies of heritage enhancement, cultural routes and e-tourism promoted by local, regional and national institutions, the F-ATLAS project has developed an App that functions as a true Virtual Museum (Besoain, González-Ortega, and Gallardo 2022; Huerta and Navarro 2023).

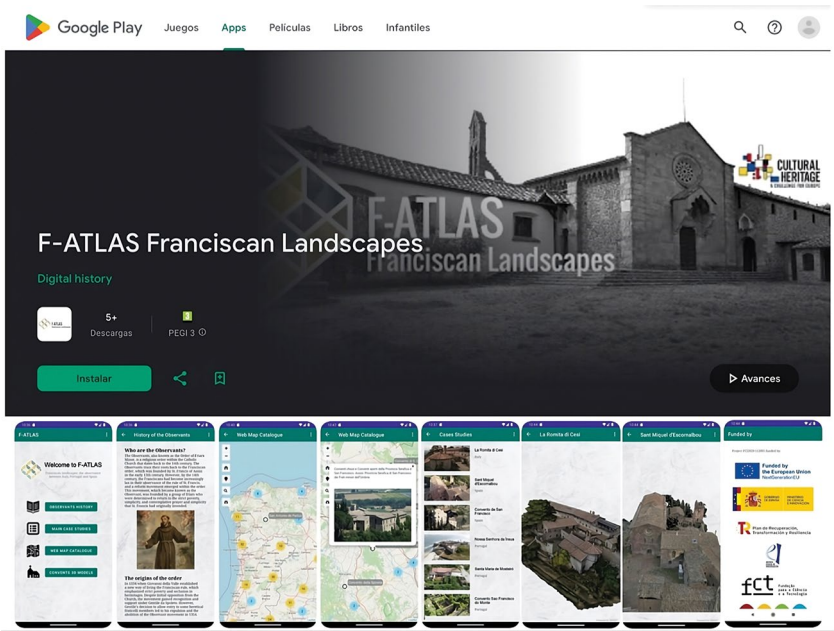


Figure 4.7: Screenshot of the F-ATLAS Virtual Museum App.

The app has been developed using Android Studio, a tool provided by Google for designing and programming Android applications. In addition, the app is built around the use of Fragments, interface blocks that can be used in different places, but also RecyclerViews, interface components that recycle the elements that are no longer visible, with a direct connection to our database. During the development process of this app, we have followed the requirements and quality standards set by Google⁴, whose platform (Google Play) facilitates the download and installation of the App on all Android mobile devices, ensuring both the quality and security of the product for the end user.

The interface design aims to promote the dynamization of the monumental heritage of European Observant Franciscanism both “on-site” and “off-site” from the monastic complexes, regardless of the user’s location. The Virtual Museum App (see Figure 4.7) has a main screen, which provides access to various sections or blocks: a brief overview of the historical trajectory of the Franciscan Observance in Europe; adapted access to the F-ATLAS Catalog and WebMap (including database records, photographs, and plans); the detailed analysis of the most significant case studies; as well as the 3D models of the convents that have been virtualized. The *3DHop* software, an *open-source* library for the creation of interactive presentations of virtual models, has been used to visualize these three-dimensional models. Finally, the app includes three additional screens that provide information about the F-ATLAS project and its research team.

4.5 Conclusions

The development of integrated and coherent approaches to the preservation of tangible, natural, and intangible cultural heritage emphasizes the interdependence of the various disciplinary fields, not by limiting the study of cultural heritage to the built one but also by considering its social value to the community. It is essential to account for the cultural context and the active communities within the territories under investigation, which must be involved in the governance strategies through a participatory and community-based approach.

⁴ The app is compatible with Android devices and is available for free download on Google Play, <https://play.google.com/store/apps/details?id=com.fatlas.f_atlas>, accessed February 20, 2025.

The F-ATLAS project, through its innovative approach to the analysis of historical documentation related to the Franciscan Observant Landscapes and the digitization of sources and architectural evidence across the territories of three European countries (Italy, Spain, and Portugal), has identified critical gaps and contributed to finding solutions through the effective use of digital resources. In this regard, the conservation diagnosis carried out on some of the buildings studied constitutes a highly valuable transfer tool for those responsible for the custody and maintenance of monastic complexes.

This project, focused on case studies of architectures of medieval origin, presented from the beginning a character of serial settlements uniformly distributed, although with different densities across countries, spanning both rural territories and urban centers in Europe. The dissolution of the religious orders occurred primarily in the nineteenth century, the consequent abandonment and sale by the State of significant assets, in addition to climatic factors, disasters—such as the recent earthquakes in central Italy—have determined the precarious conservation conditions of many of these buildings. As a result, current and sustainable strategies for the conservation and management of this highly vulnerable heritage must be defined. These complexes, often located in peripheral rural areas distant from urban centers, exemplify in an emblematic way the problems of peripheral or marginal regions and contribute to the definition of a critical conservation map.

The development of strategies for digitalizing medieval heritage aims to reach some proposals related to the development of new strategies for the use of heritage through ICT (Information and Communication Technologies) and innovative methods of exploration and interaction with the cultural heritage, such as, for example, through the identification of equipped cycling and hiking routes. The expected results will foster awareness of European citizenship based on shared values and common goals and promote a better understanding of European history based on the importance of this physical heritage, “architectures of the spirit” with intangible values and naturalistic aspects of great interest.

The growing need for remote access to information, which became evident during the pandemic period, combined with the urgent need to develop more forward-looking and sustainable tourism management tools, makes the data acquired from digital surveys not only valuable databases for the management and knowledge of the heritage, but also potential dissemination tools.

This is facilitated by modern technologies related to E-tourism and virtual tourism, such as augmented reality (AR) and virtual reality (VR), which are considered powerful means of cognitive communication.

In conclusion, databases, WebMaps, applications and surveys are the basis for heritage management according to a contemporary perspective. Digital surveys provide the essential basis for documenting the state of heritage sites, and when linked to a comprehensive assessment of structural conditions and conservation needs, they can help define a correct methodology for the conservation of the architectural artifacts within their own cultural and historical landscape.

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