Analysis processes of the vaulted system of the cloister of the Monastery of San Juan de Los Reyes through photogrammetric surveying

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Abstract

The article presents the results of the architectural survey campaigns and the subsequent graphic representation and modelling of the Monastery of San Juan de Los Reyes in Spain, with particular focus on the compositional elements of the cloistered vaulting system. The research focuses on documenting the geometric-proportional rules of the construction and decorative elements, which are essential for understanding the architecture analysed. Using integrated survey techniques, through terrestrial and aerial photogrammetry, point clouds and textured three-dimensional models were generated, derived from polygonal meshes, which were subsequently processed to generate representative plans and sections. Taking as a reference the methodology applied in the 17th century by the architect Guarino Guarini, who emphasised geometric simplification and synthesis analysis, the objective of the research is not only the collection of digital data, but also their interpretation through different interpretations, promoting an understanding and dissemination of the analysed architectural heritage that is based on the concept of discretization of the acquired data, according to both the theoretical and practical knowledge of the operator, in order to reduce occlusions and improve the graphic representation, communication and dissemination of the acquired information.

1. Introduction

The research presents the results of the architectural survey campaigns and the subsequent representation and graphic modelling of the Monastery of San Juan de Los Reyes in Spain, focusing on the analysis of the compositional elements of the cloistered vaulting system, characterised by a dual component of built and natural heritage.
In the processes of documenting architectural heritage, the search for geometric-proportional rules is fundamental in order to understand the constructive and decorative elements that make up the architectures analysed.
As is well known, with the passage of time, the techniques for collecting and transmitting information change constantly, following scientific and technological progress. It is, however, important to identify elementary representational techniques by placing a precise delimitation on the graphic contents, demonstrating an ability to filter information, in order to communicate according to a mode of generation and propagation of data relative to the reality that surrounds us.
Treatises such as Guarini's Architettura Civile (1737) propose studies on the types of vaults and the generative techniques employed at the time, focusing on geometric genesis based on primitive solids and thus on elementary and linear signs, the

Figure 1. Drone view of the cloister and roofs of the Monastery of San Juan de Los Reyes.

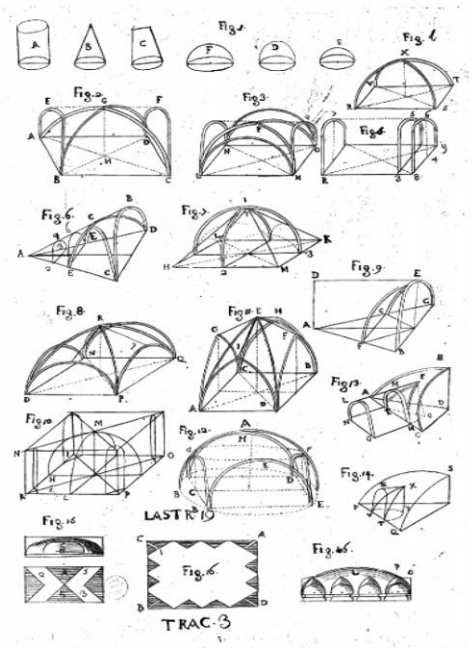

Figure 2. Identification of primitive solids and the vaults generated by them, Guarini G., 1737, plate XIX.

study of which can now be studied in depth and related to a filtering of data to be acquired, processed and communicated with digital modelling techniques that allow the construction of these theoretical models (Fig. 2). In this regard, taking the analytical and representational methodology of architect Guarino Guarini as a reference, it is interesting to emphasise the analytical approach of discretizing the acquired data through the theoretical and applicative knowledge of the operator (Vagnetti, 1970). This process of geometric simplification and synthesis analysis aims at the identification of standardised data

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acquisition techniques, in order to both avoid occlusions during the photogrammetric phase and the subsequent generation of point clouds, and to identify building types and represent them simply and directly, based on graphic and communicative completeness.
As is well known, the religious complex, located in the city of Toledo, consists of a Church and a Monastery with a 13th century cloister (Fig. 3). The architectural achievements have decorations that can be traced back to the Elizabethan and Flamboyant Gothic styles, which flourished in the last phase of the 15th century.

Figure 3. Views of the Cloister of the Monastery of San Juan de Los Reyes. Left, drone view. Right, the vaulted system.

In order to document the religious complex, from the geometric-architectural scale to the scale of greater detail, the consolidated practices of the discipline of architectural design related to the representation of the interior and exterior spaces of the worship environment were applied following a preliminary analysis outlining the data acquisition project. Therefore, different surveying techniques were employed, using photographic instrumentation by means of digital camera and four-wheel drone. The phases of the survey, carried out with terrestrial and aerial photogrammetry, made it possible to create a point cloud and three-dimensional model from textured mesh, which was subsequently processed and imported into further software for the creation of plans and sections, so as to further interact with the primary data obtained, in order to obtain additional information to feed the understanding, knowledge and dissemination of the data. Such established phases of the representation discipline, including manual and digital surveying, point clouds, planar surface processing, and 3D modeling, represent constants that define a knowledge pathway aimed at disseminating a broad range of experimental cases.
As is well known, over time, techniques for collecting and transmitting information constantly evolve, following scientific and technological progress. Constant technological development is a fundamental means for achieving comprehensive knowledge, characterized by accurate data and detailed information. However, if not properly managed, it can become a rigid and constraining element, limiting critical and subjective perceptions. This shortcoming arises from the possibility of proposing representative models—i.e., graphics generated entirely by digital tools—without the critical input of the operator, who becomes merely an executor of the technological procedure. The architectural surveying process, on the other hand, enhances the graphical characteristic of reality reproduction by systematizing the activities of surveying, documenting, analyzing, interpreting, and communicating. This method of generating and propagating data is synonymous with knowledge, both personal and advanced. It is complemented by advanced two-dimensional outputs capable of satisfying critical-interpretative analytical insights.
This perspective determined the phases of the research and the objective aim characterised, not only by a mere acquisition of digital information, but by an interpretation of the data through various interpretative lenses (Zerlenga, Cirafici, 2023).
The survey, in fact, proposes an analysis of the Spanish case study that, starting from the analysis of archival sources and integrated survey techniques, aims at the knowledge of the property, accomplished through the documentation of the spaces, the geometric analysis of the modular vaults, a synthesis representation of the vaults' curvatures and digital modelling for both a two- and three-dimensional visualisation of the architectural components of the place of worship (Bertocci, 2020).

2. State of the art

In order to outline the critical and theoretical aspects of the survey apparatus, a prior bibliographic and iconographic analysis of the case study was conducted. The research carried out revealed a large amount of iconography of the city of Toledo where the Monastery of San Juan de Los Reyes can be identified in its position above the cliff to the west of the city of Toledo. Bibliographic analysis revealed the relationship between the Franciscan congregation and the Roman Papacy in letters and writings of conversations with the Holy See. (Sanchez Gonzales, 2017)
The church, the monastery and the 13th-century cloistered area, which has been remodelled several times after collapses and a fire in 1800, make up the religious complex. Each of the architectural elements, which characterise the rooms, highlight the eclectic style of the structure, presenting decorations in the Elizabethan and Flamboyant Gothic styles that characterised the late 15th century. The phases of the survey, carried out with terrestrial and aerial photogrammetry, made it possible to create a point cloud that was subsequently modelled to create plans and sections. In order to document the religious complex, from the geometric-architectural scale to the scale of greater detail, various surveying techniques were employed, using photographic instrumentation by means of a digital camera and a four-powered drone. The camera used (Nikon D3200) was employed to acquire images with high definition and sharpness, in particular for the foreground and some architectural details, following the convergent axis method, while the entire volume was surveyed from the drone (DJI Mavic Mini 2), with particular attention to the upper crowning portion, which is difficult to reach. The description of the structural geometries and sculptural apparatuses constitutes a first critical result of the constitution of the representative model (Brusaporci, 2023), which becomes a tool for the graphic documentation of the Monastery of San Juan de Los Reyes.

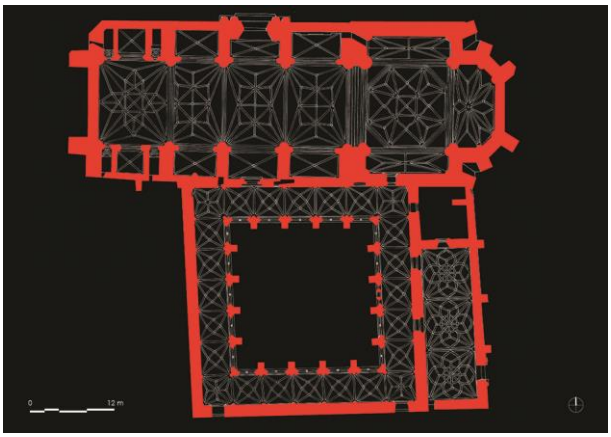

Figure 4. Plan of the religious complex of the Monastery of San Juan de Los Reyes.

Following the analysis of the field of investigation, the purposes of data collection were extrapolated according to the scale of representation. What emerged was a methodological comparison between techniques and instruments where the work of the architect, rich in skills and knowledge, intercepts the instrumental data in order to derive the information regarding the data for digital representation (Salerno, 2017). The process described, proper to the discipline, allows the choice between the infinite points of instrumentation, in relation to the activities to be carried out: in fact, it is the role of the draughtsman to discipline the graphic and numerical data to determine the result of the survey.

The church, a granite ashlar construction, has a single-nave floor plan (Fig. 4), measuring 56 metres in length and 21 metres in width. At the end of the nave, characterised by multiple chapels positioned between the buttresses, there is a polygonal presbytery and a raised choir. As is well known, the graphic representation makes use of archive documentation, identified in the graphic tables of the monument's original design and in the notebooks of the workers who crowded the building site over time, leaving traces of their work in the work journals. They are a valuable contribution to the survey activities as they preserve the history of the construction and the inevitable events that characterised the building.

Analysis of archive documents revealed that the main entrance was originally built on the side opposite the presbytery, on the west wall, of which no trace remains inside. Externally, there is an imposing granite wall with a large opening, the apex of which is characterised by the bell tower consisting of three openings on four pedestals ending in pinnacles.

The north façade, on the other hand, is characterised by two different areas. In the first, up to the transept, is the entrance door, designed by Juan Bautista Monegro and completed in 1607 with Gothic and Renaissance elements (Fig. 5). In the upper part, there are four large windows corresponding to the side chapels inside the church, surmounted by sculptures with crests and pinnacles. The second area, on the other hand, features a series of eight pairs of ornamental arches, surmounted by a panel, and in the upper area two more pairs of openings divided by mullioned windows with two lights.

Figure 5. View of the main entrance elevation to the Monastery of San Juan de Los Reyes.

Further interest was paid to the elements of detail determining the graphic representation of the architectural context. The cognitive process, in fact, took into account both the formal aspects and the decorative features that characterised the century of construction.

The apse is characterised by the presence of six large pillars, which flank the continuation of the double row of arches and their respective chains. These structural elements are lightened by the decorations with stylised pinnacles housing six pairs of royal iconographies in their centre. The space is surmounted by an octagonal dome, with openings on each of its eight faces, alternating with pillars ending in soaring pinnacles.

Leaving the church, through a portal on the southern wall, one enters the cloister. Almost entirely rebuilt, following the extensive damage caused by the fire in 1800, the cloister has a quadrangular floor plan of 22 metres per gallery, covered by five vaults on each side, for a total of 24. It is composed of two superimposed floors with geometric and structural differences such as the design of the vaults and their discharge on the side walls, the decoration and the type of openings.

The pillars of the lower cloister are decorated with grotesque motifs, elements freely taken from classical antiquity, characterised by plant and fantasy forms intertwined with human and animal figures, set in fantastic landscapes and architectural perspectives, also following profane themes far from the ecclesiastical world.

The columns are divided by five large windows with their mullioned windows adorned with tracery in the stone that divide them into small arches from which the central garden can be seen. The ribbed vaults, like those of the adjacent church, do not cross the keystones, but form lozenges.

Access to the upper floor is via a staircase in the Plateresque style, an artistic order developed in Spain between the 15th and 16th centuries, designed by Alonso de Covarrubias during the reign of Charles V. (Sanchez Gonzales, 2017) The vertical connection is surmounted by an imposing coat of arms, of the family that financed the work, representing a double-headed eagle at the base of the lowered dome, characterised by a rose window that serves as a keystone.

The upper cloister, the same size as the one below, has some decorative and structural differences. The ceiling is lower and does not feature a vaulted roof, but is a coffered surface of painted inlaid wood. This structural and decorative difference is reminiscent of the recurring Moorish art, in which the arches crowned by pairs of lions cross the gallery. The openings are mixtilinear pointed arches with stone balustrades overlooking the central garden (Fig. 6).

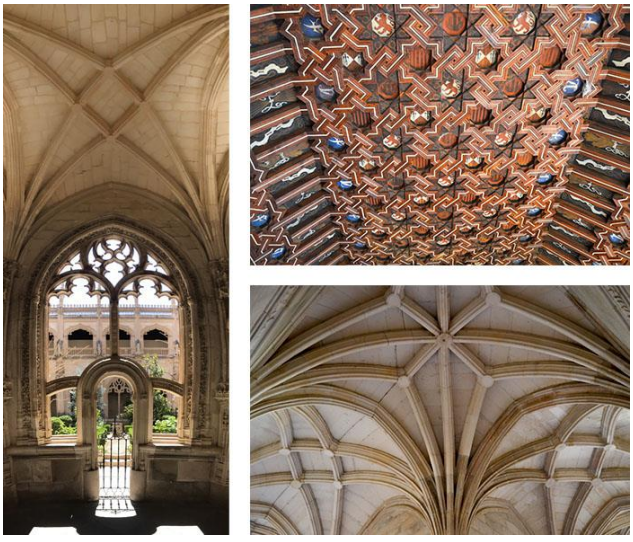

Figure 6. Vista del chiostro del Monastero di San Juan de Los Reyes. A sinistra l’ingresso al chiostro dal corridoio voltato. A destra, in alto: copertura in cassettoni in legno intarsiato dipinto per il primo piano; in basso: copertura a sistema voltato.

3. From survey to modelling for the documentation of monastic spaces.

In order to graphically document the Monastery of San Juan de Los Reyes, the consolidated practices of the discipline of architectural design related to the representation of the interior and exterior spaces of the building of worship were applied, paying particular attention to the cloistered area of the religious complex. This perspective determined the phases of the research and the objective aim characterised by a limited three-dimensional visualisation in favour of the interpretation of the data. The survey, in fact, aims at the knowledge of the asset, accomplished through the documentation of the spaces and digital modelling, considering the hyper-accessibility of tourists and curious people who daily flock to the Monastery in compliance with the limitations related to the different religious functions (Campi et al. 2016). We therefore proceeded to a geometric and spatial knowledge with the use of an analytical methodology, starting from an analysis of the archival documents, found in situ, and then proceeding with a graphic documentation through the survey. The methodological phases relating to data acquisition involved a precise choice for the representation of the artefact (Remondino, 2011). The aim of the contribution is to integrate the digital images with the point cloud and the two-dimensional drawings extrapolated from the digital relief model. The precise decision was made to show the most representative images in relation to the sacred space: the cloister is drawn in the two-dimensional spatial configuration and subjected to red colour meshing in order to contrast the photographic and photogrammetric image. The result displays a series of graphic representations derived from the survey itself and subsequent interpolations with computer tools. The choice of the type of survey to be carried out was determined by the analysis of several factors: the survey site being characterised by a high altitude, the complex being built on a rise overlooking the city's belvedere, an area subject to multiple constraints, caused several interferences during the acquisition phase of the drone shots, compromising the initial flight plans.

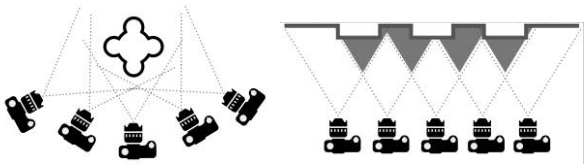

Figure 7. Synthetic diagram of photographic shooting technique with converging axes on the left and parallel axes on the right.

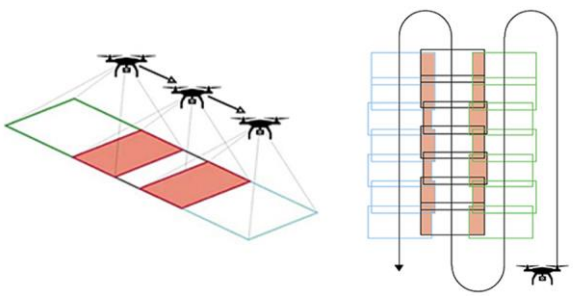

Figure 8. Synthetic diagram of photographic shooting technique with UAV Sistem.

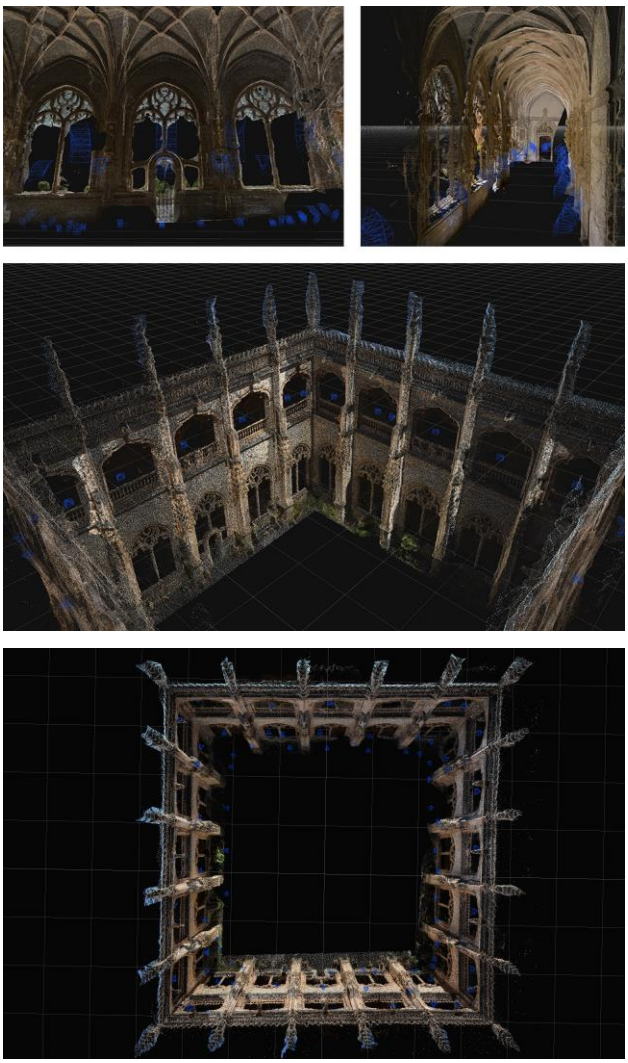

Figure 9. Cloister of the Monastery of San Juan de Los Reyes, dense point cloud generated by the photogrammetric process.

Therefore, for the purpose of the photogrammetric process, it was decided to integrate the use of different surveying techniques into a single project (Fig. 7), by means of photographic instrumentation, digital camera and four-powered drone (Fig. 8), attempting to alternate the various techniques according to the different objectives of the survey (Zerlenga et al. 2023). The lack of freedom of movement, caused by the small size of the cloister in width and the verticality underneath the vaults, greatly affected the survey campaign and the processing of the collected data. (Corniello, 2020) The captured images were interpolated with measurements taken at three different points. In order to implement this methodology, it is necessary to carry out a flight plan programming in order to obtain a complete restitution of the area analysed. Therefore, a vertical and horizontal grid was proposed with modules having an overlap compatibility of at least 70%. Shots were taken in manual mode along each vertical and horizontal axis of the grid, varying the distance from the artefact to be acquired. The survey was performed both from the centre, perpendicular to the cloister pillars, and at the side points in order to collect the greatest number of triangles for the realisation of the model.
In particular, different photographic techniques were employed, both with converging and parallel axes, depending on the volumetric conformation and architectural characteristics of the spaces analysed. The first technique was used in particular for

the acquisition of data relating to the first floor, characterised by rooms composed of different elements, such as multi-styled pillars that punctuate the mullioned openings with different decorations, surmounted by the vaulted system that acts as a roof. The parallel axis technique, on the other hand, was used for the first floor, in particular by positioning the point of photographic acquisition in the centre of each ogival arch window. This technique was used for each corridor, which make up the sides of the quadrangular cloister.
Both the techniques employed in the terrestrial and aerial photographic acquisition phases were integrated into a single work project in order to obtain instrumental reliability, both in terms of metric quality and descriptive and qualitative correspondence in relation to the analysis of the architectural artefact, the point clouds generated by the interaction of different instruments compatible with each other, were inserted within a single reference system.
Specifically, the different point clouds (Fig.9) of the various environments, obtained from the different acquisition processes, were compared and united in a single project. Numerous difficulties emerged from the generation of the survey models, such as occlusions of some portions of the building and various losses of GPS signal from the drone in some areas, resulting in several gaps (Barba, 2020).
This error was resolved by merging different point clouds generated by acquisition and processing processes at different scales of detail into a single project, choosing common targets. Following the acquisition of the images, we proceeded with the photogrammetric process using 3D Zephyr software.
This technique is developed with the interpolation and management of georeferenced three-dimensional data with the generation of point clouds.
The operational sequence is based on several stages to generate a queryable textured mesh model of polygonal mesh, based on the dense cloud data in relation to the alignment of the captured images.The workflow starts with an algorithm that evaluates the camera's internal parameters, such as focal length, radial and tangential distortions, the positioning of the camera for each shot, and the sparse cloud.
In the next phase, additional pixels are reprojected for each aligned camera, creating the Dense Cloud (Fig. 10). Moreover, with the Build Mesh phase, a polygonal mesh model is generated based on the dense cloud data. Finally, the polygonal model is textured in the Build Texture phase (Apollonio, 2021).

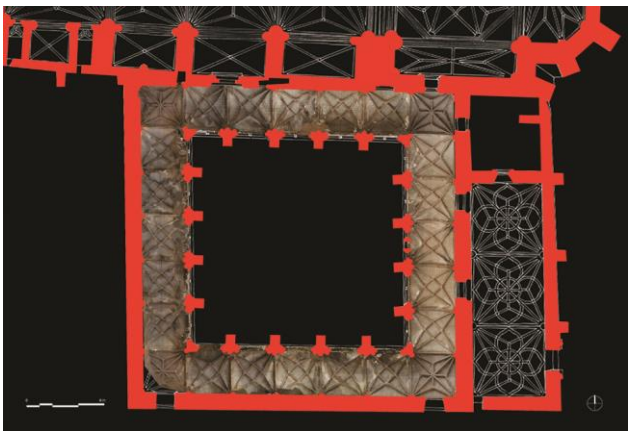

Figure 10. Cloister of the Monastery of San Juan de Los Reyes. Planimetric survey of the church and the cloister, with a detail of the vaulted system, obtained through the photogrammetric process.

In the subsequent phase, the data is exported to the 3D modeling software, and the digital model is sectioned with a cutting plane to obtain the two-dimensional drawings (Fig. 11).
The final editing takes into account both the digital capabilities of the tools used and the possible interpolations by the author (Fig. 12). In fact, an analysis of the collected data was necessary in relation to the previously expected survey model result, and the superfluous data were removed according to the disciplinary phases. The final result is an analysis that minimizes the margin of error, with the aim of optimizing the capture time and ensuring the creation of highly reliable survey data. (Corniello, Lento, 2022).

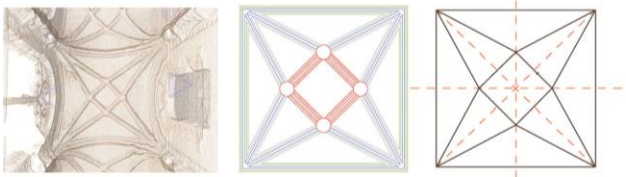

Figure 11. Cloister of the Monastery of San Juan de Los Reyes, graphic synthesis process for identifying the basic geometries of the vaults.

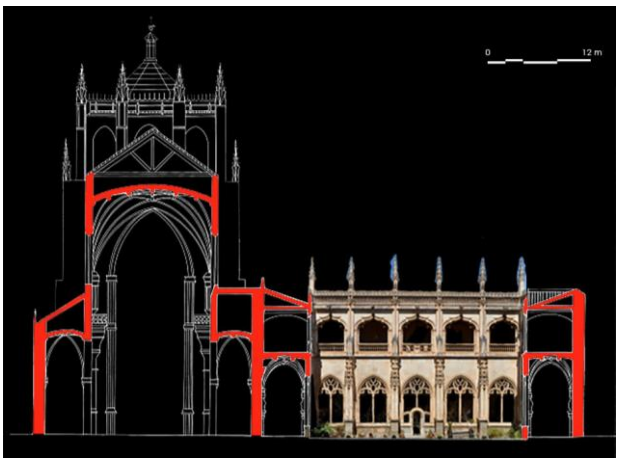

Figure 12. Transversal section of the church and cloister of the Monastery of San Juan de Los Reyes.

4. Conclusion

The research aims to focus on the technological prerogatives of architectural surveying and the analytical methodologies employed, emphasizing the fundamental relationship between the past and the future. It involves analyzing treatises related to the study of the architectural typology under examination and the digital technological development for data acquisition and subsequent representation for dissemination purposes.
The planning of the survey project, the tools used, the processing performed, and the digital elaboration presented represent a precise graphic choice capable of satisfying the proposed 3D representation in relation to the studies conducted, from archival documentation to the survey model. The surveys and representative models carried out on the Monastery of San Juan de Los Reyes are intended to meet the needs of architectural analysis, including through virtual and technological processes (Fig. 12), to promote knowledge through critical thinking and to enable the creation of precise documentation with results in new European contexts, enhancing accessibility and the discovery of resources through new perspectives. By using a method of geometric interpretation and comparing the synthesis method applied by Guarini with today's applications, it is demonstrated how these

techniques, even after centuries, allow for defining the survey as a powerful tool for scientific investigation. This approach takes into account the importance of the relationship between the quantity of acquired data and the respective quality on which the results are based.
These results, in turn, no longer rely on the massification of information but, in contrast, follow Guarini's vision, where architecture is reduced to its geometric and elemental matrices, both in the survey phase and in the elaboration phase, through the discretization of information, and in the representation and graphical analysis phase up to the dissemination of the data.
In fact, this activity does not aim to illustrate all parts of the monastery but, by focusing particular attention on the cloister, aims only to describe the peculiarities identified during the knowledge phases through architectural drawing. The surveys and representative models carried out on the Monastery of San Juan de Los Reyes are intended to meet the needs of architectural analysis, including through the virtual and technological process, to enable the creation of precise documentation (Cicalò, et al. 2021) with results in new European contexts, enhancing accessibility and the discovery of resources, but above all, promoting knowledge through critical thinking.

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