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ANALYSIS OF DESIGN PATTERNS IN BUILDINGS WITH OVERLAPPED ARCHITECTURES. CASE STUDY: THE CATHEDRAL OF VALENCIA

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ABSTRACT:

The aim of this paper is to focus attention on the methodology used to carry out geometric analyses, based on digital models, of the different construction stages that are juxtaposed in the most emblematic building of the three selected in the study, the Cathedral of Valencia. These analyses will be the basis for the subsequent modelling of the building in each of its historical periods. It is an extremely complex building which its works began in 1262. Over the centuries it has been accumulating extensions and reforms adapted to the new architectural styles of each era. In this communication, the methodology used for the collection of massive data in this complex building will be exposed, making special mention of the different equipment used in each case, the programming of tasks, their coordination and the digital models obtained. Likewise, the process of carrying out the geometric analyses of each of the construction stages will be exposed. Lastly, the results obtained will be presented taking into account the possible geometric and proportional links that the successive interventions have given rise to.

1. INTRODUCTION

1.1. Background

To carry out a deep study of a heritage architecture, it is necessary to carry out multiple analyses. Each of them provides data on different aspects related to historiography, spatial organisation, building techniques, evolution, pathology...etc. There is a type of analysis that, in many cases, does not have the importance it deserves, the geometric analysis. These studies provide data that, together with other types of sources, can be very illuminating to determine the original project of the building. The geometric analyses provide data related to the original projective idea of the author, as well as the interventions over time (Soler, 2014). These analyses consist of determining the regulatory layout used by the author of the project to compose and design the entire building. This process can be more or less simple when it comes to how it has been built. However, these analyses can be much more complex when the building counts with a number of interventions carried out by different authors at different times. In each of them, very different functionalities and stylistic programs are addressed, which is why the geometric analyses tend to vary considerably from one moment to the next. These proportional differences in the design of the different construction stages are what help to differentiate the elements that correspond to each one of them (López and Germes, 2019). It is very interesting to add metrological analyses to these graphic analyses. The latter consist of determining the measurement system used by the author of the project. Until mid 19th century, there was no unified measurement system (decimal metric system). Different measurement systems were used in each geographic area. In the case of Spain, it is possible to identify different metrological systems between towns located at small distances. These data, which at first may seem chaotic and disorderly, contribute very effectively to the discovery of the different authors who could have collaborated in the layout of the same building, even in the same construction stage. There have been cases, such as the church of San Miguel de Foces (Ibieca, Huesca, Spain), in which two clearly differentiated construction stages have been detected because the measurements of the elements that compose them were adjusted to two clearly differentiated metrological systems (Aragonese and Valencian).

It is, therefore, very useful to carry out metrological and geometric analyses when studying buildings with overlapped architectures, since the results obtained will effectively contribute to detecting each of them.

There is a substantial impediment for these analyses to be reliable and truthful: it is absolutely necessary that the spatial and metric data collection carried out is absolutely rigorous. This condition is not easy when it comes to complex heritage buildings. It is necessary to resort to massive data collection methods by 3D laser scanner (TLS) or photogrammetry. The digital reconstruction method on data derived from a terrestrial laser scanning (TLS) campaign has been sufficiently tested in the development of geometric analysis of complex architectures (Spallone et al, 2021).

1.2. Objective

This communication intends to focus attention on the methodology used to carry out the geometric analyses, based on digital models, of two of the different construction stages that overlap in the most emblematic building of the city of Valencia: the metropolitan cathedral. These analyses will be the basis for the successive modelling of the building in each of its historical periods. These are the two least studied stages geometrically and whose graphic analysis provide information on the projective process followed by the author of the original design (13th century) and the following intervention carried out in the 14th century. Both stages are framed in the Gothic style, although the

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first corresponds to a primitive Gothic and the second to a late Gothic style.

This study is carried out for the first time using reliable and rigorous metric, geometric and morphological data. Different geometric studies have been carried out previously. (Navarro, 2003) (Soler, 2014). All of them have been based on surveys made using traditional techniques, taking measurements on the neoclassical elements that cover the Gothic structures. Only one graphic study of the transept and ambulatory prepared by the authors based on the data obtained with the 3D laser scanner has been carried out, where it was possible to verify that the results differ from those previously established. (Authors, 2023)

1.3. The case study

Valencia Cathedral is an extremely complex building. Construction began in 1262 (Hinojosa, 2014). Over the centuries it has been accumulating extensions and renovations adapted to the new architectural styles of each era, which makes it a didactic example of the different stylistic expressions that have been produced: Romanesque, Gothic, Renaissance, Baroque and Neoclassical (Viñals and López, 2022). The best architects and artists of the moment worked in each of the renovations and extensions carried out. In all of them it was intended to hide the structures of past times. In the 20th century, an intervention was carried out in which part of some of these actions were exposed, which is why nowadays the Valencia Cathedral is an example of twinned and juxtaposed architecture. Some architectural elements belonging to the primitive temple and to the later late Gothic intervention have been uncovered and can be seen completely independent from the rest of the interventions. However, in most of the interior spaces and on the façades, the renovations and extensions are superimposed, which means a high degree of difficulty when it comes to establishing the geometric and proportional canons used in each of them. Thanks to the last intervention, in which part of the Gothic structure was discovered, it has been possible to take data from the first construction stage. The ambulatory, the transept and the nave (central and two laterals) belong to it. The side chapels that we see today are the result of later interventions. Also in the Gothic style, but built in the 14th century, are the dome, the current bell tower, colloquially called the Miguelete (1381) and the Chapter House, which currently houses the Holy Grail. Both constructions were entrusted to the master Andreu Juliá.

Figure 1. View of the interior of the cathedral.

The original temple was designed by Arnau Vidal (Sanchis, 1933). It proposes totally new traces for the header through the use of ambulatory and peripheral chapels using a solution in the ambulatory until then unknown. This significant and exceptional element makes the Valencian Gothic cathedral a pioneering and avant-garde building at the time. The rest of the plan conforms to a more Cistercian approach with three naves and a transept, covered with ribbed vaults and bricks for severy. On it stands the octagonal dome designed by Nicholas of Ancona in the 14th century (Segura, 1971). It is, without a doubt, the most remarkable element of the temple (Street, 1865) and the most admired throughout the centuries.

Figure 2. View of the dome from inside the cathedral.

The chapel of the Holy Grail (1365-1369) was built entirely in stone and covered with a splendid star vault. Originally it was exempt from the temple and the old bell tower was located next to it. This was demolished to build a new exempt one (1381-1418) popularly known as the Miguelete or Micalet due to the name of its largest bell. It is perhaps the best known and emblematic architectural element. It has an octagonal plan made up of four bodies of identical height separated by a perimeter cornice until it crowns a height of 51 m (225 Valencian palms), being for centuries the tallest tower in the city. In the construction intervened Masters of the *carving* of Pere Balaguer, *a well-known master in the art of stone*, author of the Serranos' Tower, intervened in its construction. (Llorente, 1980) and so Martí Llobet. The result conforms to the late Gothic aesthetic using gables, alfices, openwork tracery and other ornaments that give it great beauty. In 1458, the chapter decided to expand the cathedral by the feet so that the bell tower and the Chapter House would be incorporated into the temple. This great work was commissioned to Francesc Baldomar, the most original master of Valencian medieval architecture (Bérchez and Zaragozá, 1995).

This stylistic, spatial even accessibility diversity of the different rooms that compose this complicated construction made it necessary to reconsider a methodological strategy to address the massive data collection aimed at preparing a real, rigorous and exact planimetry. On the digitalisation of the information obtained, it has been possible to carry out graphic analyses whose results have allowed us to specify the ratio existing between each of the elements studied, as well as to determine the construction process that was followed in the original stage and the geometric games carried out to situate the bell tower and the Holy Grail Chapel.

Figure 3. The bell tower (Miguelete) and the Chapel of the Holy Grail.

1.4. Methodology

Geometric analyses are not reliable if a rigorous survey of plans is not available. Therefore, in first place, a data collection using a 3D laser scanner was considered as the fastest and most reliable method. The digitisation of the obtained point clouds could be done by vector or parametric methods. The option of parametric digitisation was taken because it allows the configuration of architectural elements and spaces in 3D. This is a great advantage when proposing geometric analysis since in a single view it is possible to include the geometric traces or schemes in plan and the mountains or vertical layouts. This confluence of geometric resources in a single graphic representation allows establishing direct correlations between traces and mounts. The vector representations are constituted as independent views whose correspondence is not direct.

After the parametric digitisation, we proceeded to the geometric analysis of the spatial structure of the temple. In first place, the study to obtain the regulatory layout that gave rise to the design of the original building was addressed. This regulatory layout constitutes the topographic base on which the entire compositional and proportional design of the Gothic temple is based. As they are juxtaposed architectures, the geometric analysis of the next construction stage was carried out, testing with the same regulatory layout used in the first. The results obtained, as will be seen in the course of this paper, were surprising and allowed us to establish conclusions regarding the deep geometric knowledge of the authors of the projects.

2. DATA COLLECTION AND 3D DIGITISATION

2.1. Data collection with TLS

The Valencia Cathedral has been analysed from multiple aspects: artistic, constructive, historical, social, sacred, etc. Plans have been surveyed for their metric and geometric documentation on various occasions. However, it has always been about planimetry carried out with traditional methods, with considerable margins of error in some cases and with the limitations that arise from a survey where only the section plans made are documented. One of the purposes of this research has been to undertake a rigorous survey, using digital technology to truthfully document this complex building. The laser scanner has the ability to capture the geometry of the scanned element with excellent dimensional precision (Molina et al, 2021) and with an extremely accurate description of the morphology of the surfaces. It allows you to capture the entire detailed model of an architecture (Owda et al., 2018). Different types of operators were used, depending on the spatial and environmental characteristics and circumstances of each space or enclosure: In large spaces, the Faro brand scanner, model Focus Premium. This scanner has a range of 360 m and its margin of error is 4 mm, so it perfectly meets the established needs. In reduced spaces and complex morphologies, the Faro brand handheld scanner was used, model Freestyle. This is the case of the spiral staircases: the lack of light, the very small space and the continuous rotation forces the creation of multiple scanning stations on stepped surfaces. It was also used in the "reconditorio" or "secret chamber" located above the sacristy (Fig. 4).

Figure 4. Faro brand handheld scanner, model Freestyle.

As it is such a complex building, the scanning areas were divided as to facilitate grouping in subsequent records. A previously studied scanning program was necessary. For the complete data collection of the entire building, 573 scanning stations were needed. For the processing of the scans and formation of point clouds, the Scene program from Faro was used. In the registration of the point clouds, 130 groupings were made with a mean error of 4,1 mm. The final cloud is made up of 4.777.499.653 points.

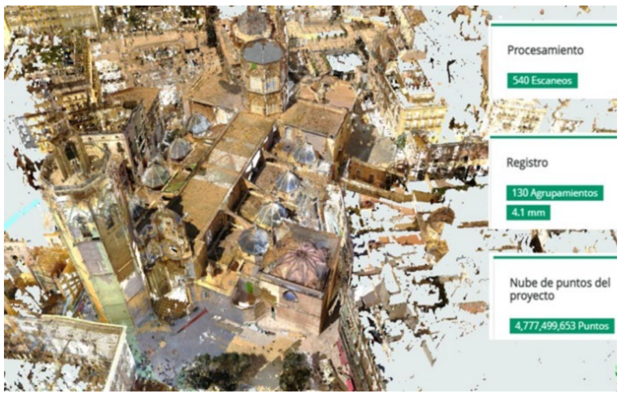

Figure 5. Map of the 573 scanning stations.

Figure 6. Cathedral point cloud.

2.2. Parametric digitisation

Based on the precise information generated in the data cloud, the floor plan of the temple was digitised in a three-dimensional model, using the BIM Autodesk® Revit software.

To carry out the geometric analyses of the two construction stages under study, the temple was sectioned at a height of 4 m. Since it is about analysing the construction stages related to the original temple (18th century and the subsequent late Gothic intervention of the 14th century, only the elements belonging to these two stages were digitised, deleting the architectural elements belonging to later interventions. For this, it was necessary carry out an analysis work based on the data of the current building. The main problem was the lack of information regarding the morphology of the original temple. The apse, originally French-style as in the nearby church of Santa Catalina, was closed during the Renaissance intervention and later covered during the Baroque period. Likewise, the "imafronte" façade has been lost after the 15th century intervention in which the church was enlarged to integrate the bell tower and the Chapel of the Holy Grail.In both cases the elements were digitised based on the small vestiges and on the sources kept in the cathedral archives related to the works books.

The use of BIM software allowed the analysis of the construction phases. Combining the information from the point cloud, the historical plans and the data of each of the construction elements that make up the Church. In addition, it was possible to incorporate parametric information in the geometric analysis of the building traces.

3. GEOMETRIC ANALYSIS

3.1. The geometry of the transept and ambulatory

The geometric analyses began at the head of the temple since, according to the written documents, it was in this place where the church began to be built (Dalmases and Pitarch, 1988). At the end of the 13th century, in addition to the main altar, seven chapels had been built in the ambulatory (Robres 1973: 125-126). The scaled orthophotos that can be extracted from the points cloud using the Scene program were used to make the first approximation tests to the geometry of the transept and the ambulatory.

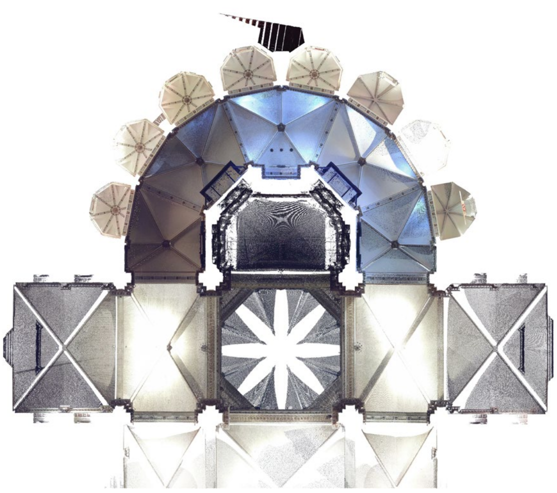

Figure 7. Point cloud of the transept, apse and ambulatory of the cathedral on which the geometric analyses were carried out.

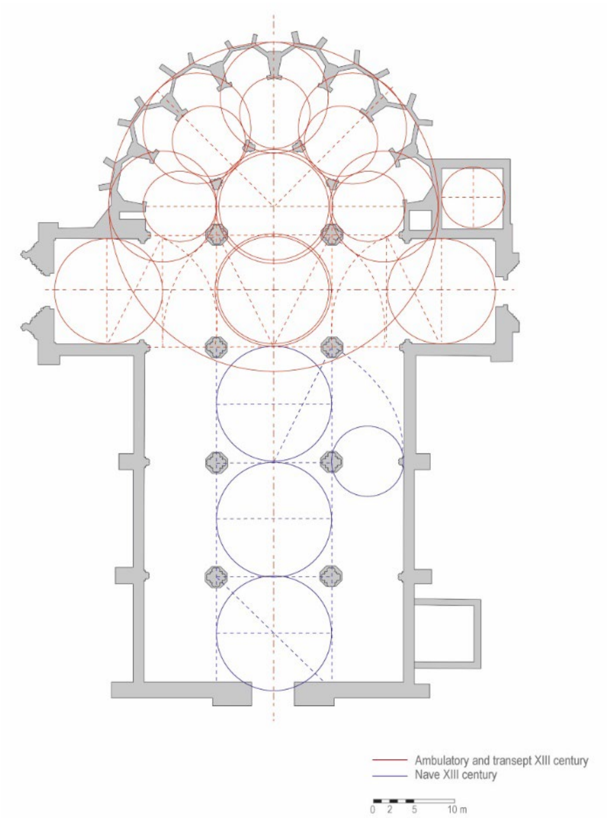

Figure 8. Digitisation of the geometric analysis of the transept, apse, ambulatory and nave.

Initially, the circle whose diameter is equal to the interior width of the arms of the transept was used. It has a dimension of 12.88 m (50 Aragonese feet, 42.5 Valencian feet). After testing the possible proportions in the transept (auron ratio, diagon, double square, etc.) it was possible to verify that the dimensions of the transept were subject to the golden ratio as can be seen in the figure.

This same circle is the generator of the octagonal apse and the ambulatory that surrounds the apse and gives access to the ambulatory chapels. The center of the apse is located in plan through the golden rectangle whose smaller side is located in the diameter of the regulating circle of the transept and its dimension is equal to half the radius. This point is constituted as the focal center of the entire ambulatory.

The shape of the plan of the ambulatory is the result of the succession of regulating circles tangent to the circle of the apse and whose center is located on the radial Cartesian axes and at 45º perpendicular to each of the faces of the octagon of the apse. The points of intersection of the circles obtained determine the octagonal sides of the ambulatory. Each of these sides breaks down into two others to give access to the double chapels.

The geometry of the chapels is obtained by tracing the surrounding circumference of the regulating circumferences of the ambulatory. Starting from the point of intersection of this circumference with the axes of the chapels, the diagonals of the obtained geometric figure are drawn. The point where they intersect is the center of the circumference in which the octagon of each chapel and keystone of the vault is inscribed, as previously stated by the authors (Authors, 2023). In this article, the authors demonstrate that the cathedral began to be designed from the transept and the apse. From these elements, using the same regulatory layout, the ambulatory and the radial chapels of the ambulatory are designed.

The tracings in the apse are also governed by the same regulating circle. The height of the apse is equal to two diameters. In this case, the floor is 58 cm (3.0 Aragonese palms, 2.5 Valencian palms), higher than in the rest of the nave. The floor of the apse was always elevated with respect to the rest of the temple to give more significance to the most sacred and main place of the church.

The dome was rebuilt in 1430 by Martín Llobet, one of the architects of the Miguelete. The primitive dome suffered serious damage due to an earthquake. In his design he continued to handle the regulating circle as shown in the figure. The inner octagon of the plan is inscribed in the regulating circle. The height of the first body arises from the formation of the golden ratio rectangle whose side is equal to the radius of the regulating circle. The height of the second body is equal to the radius of the circle.

3.2. The geometry of the ship

Advancing in the geometric analysis, it has been verified that the width of the nave does not correspond to a proportional formula, but is determined by the width of the ambulatory. The central nave conforms to the *quadratum* proportion, being the regulating circle used for the design of the transept, crossing, apse and ambulatory. The square that circumscribes the regulating circle is the one that forms each of the three sections of the central nave. With this simple geometric formula the three bays are designed.

This same regulating circle is used for the design of the tracings. As shown in the figure, the proportion of the height of the central nave is three times the radius of the circle. The arches that divide the central nave from the lateral ones have a height equal to the diameter of the circle and the center of the arch is two parts from the opposite end if the diameter of the circle is divided into five parts; and at a height equal to two parts.

3.3. The geometry of the Chapter Hall or Chapel of the Holy Grail

As previously stated, the Chapel of the Holy Grail was built free from the temple approximately one hundred years after the church was built. Its plan shape is a perfect square whose interior conforms to the regulating circle of the rest of the temple, although its diameter increases by 2 Valencian spans. This dimension could be due to a premeditated decision by the tracer, or to the fact that the measurements taken inside the temple to be matched inside the Chapel were taken along the axes of the central nave bays. This would explain this small increase in the dimensions of the Chapel of the Holy Grail with respect to the regulating circle that organises and composes the entire interior of the temple.

Its location is not random, since, according to what has been verified, the original regulating circle is used again to determine the place where it should be built, as can be seen in the figure. The geometric process followed by Andreu Juliá is based on the sequential organisation of the regulating circle of the original church following Cartesian axes, in such a way that the regulating circle is doubled on the abscissa and ordinate axis. The chapel is located exactly on the circle (2.1).

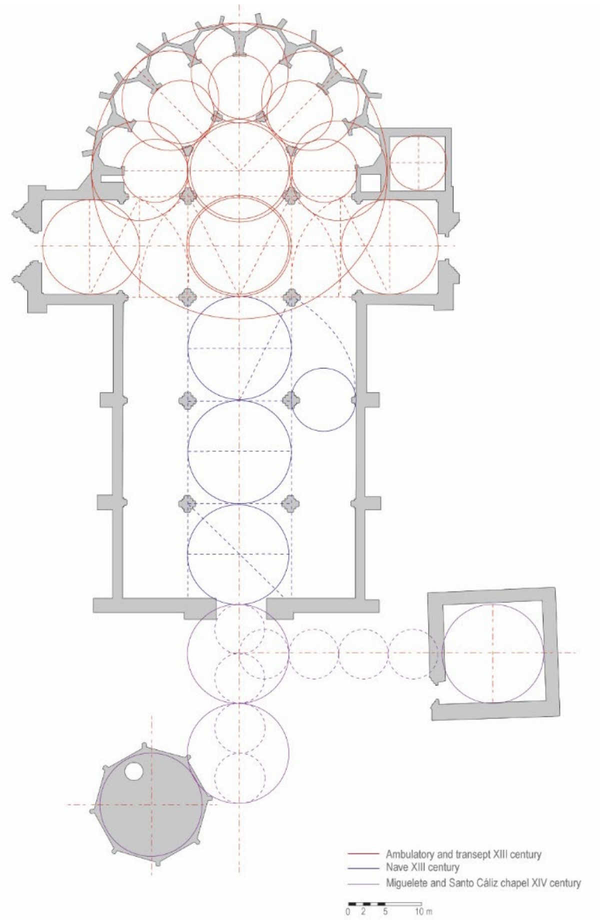

Figure 9. Digitisation of the geometric analysis of the plan with the Chapel of the Holy Grail and the tower bell (Miguelet)

3.4. The geometry of the bell tower or Miguelete

This bell tower came to replace an older one that was at the foot of the primitive temple. It was built, like the Chapel of the Holy Grail, free from the church. Its location is not random either, but obeys a geometric rule, where the regulating circle used for the design of the primitive temple is once again the protagonist.

As shown in the image, the Miguelete is located on the same axis line as the side nave. Its distance from the temple is determined by the succession of regulating circles from the central nave and from the side naves, making tangency between them.

The plan is formed by a regular octagon whose perimeter coincides with the height of the tower. The octagon is inscribed in a circle whose diameter coincides with the diameter of the circle that circumscribes the outer octagon of the dome as shown.

The turn of the octagon with respect to the rest of the plan of the temple could have been determined by the intention of Andreu Juliá to “chamfer the turn” that Miguelete street formed at this point.

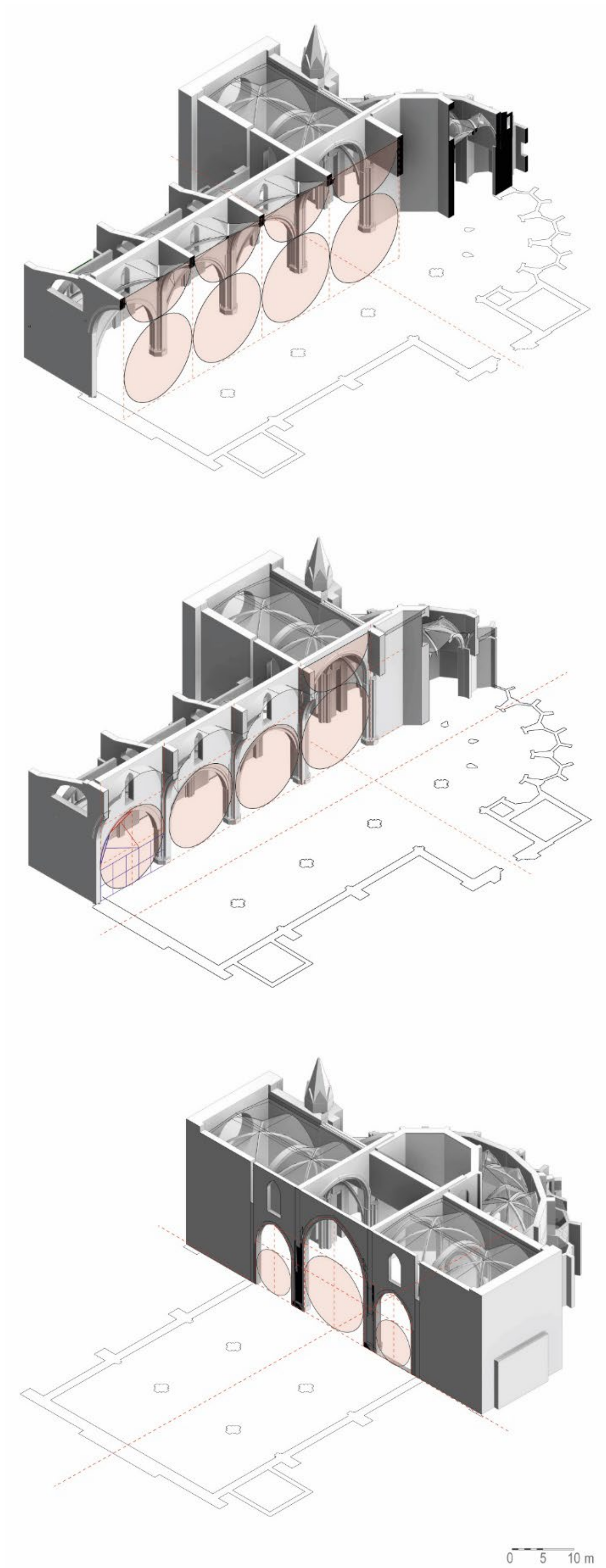

Figure 10. Digitisation of the geometric relationship between the plan and internal height of the Cathedral.

4. DISCUSSION OF THE RESULTS

After studying the results obtained in the geometric analyses, it can be established that the circle whose radius is equal to the interior width of the arms of the transept is the regulatory layout used by Arnau Vidal for the design of the transept, the apse, the ambulatory and of the radial chapels of the ambulatory. Likewise, this same circle determines the distance at which the diaphragmatic arches that divide the three bays are located, as well as the width of the central nave. The width of the side naves is not determined by any geometric game that starts from the square of the central nave, but rather is adjusted to the width of the ambulatory, which shows that the transept, apse and ambulatory were built before the nave.

When after one hundred years, in 1365, it was decided to build the Chapel of the Holy Grail and the Miguelete, the author of both projects used the regulating circle that had been used in the design of the temple to place both buildings on the lots that had remained after the demolition of eleven houses surrounding the cathedral (Sanchis, 1977). The consecutive succession of circles forming a square indicates the place where the Chapter House will be built. The same consecutive succession of circles, but in this case linearly from the central nave and from the side nave, indicates the point where the center of the bell tower should be located.

In each of these buildings the regulating circle of the temple is used again for its design. In the case of the Chapter House, a square plan is built whose side is equal to the diameter of the regulating circle plus two Valencian spans. In the case of the Miguelete, the outer circle of the dome is used to inscribe the octagon that makes up the plan.

5. CONCLUSIONS

After the analyses carried out and the results obtained, it can be concluded that the original temple, began to be built in 1262, bases its design on a studied and premeditated geometric scheme. For its preparation, a single regulatory layout was used, consisting of a circle with a diameter of 12.88 m (50 Aragonese feet, 42.5 Valencian feet). It can be said that with a nail and a rope the transept, crossing, apse and ambulatory could be redesigned.

The nave was reconsidered later since its width is conditioned by the width of the ambulatory.

The master who designed the late Gothic buildings, one hundred years after the cathedral church was built, based his designs on the same regulatory layout used in the original building. The regulating circle with a diameter of 12.88 m that was used by Arnau Vidal in 1262 was used again by Andreu Juliá to designate the location of the Miguelete and the Chapel of the Holy Grail. All this implies a deep knowledge of plane geometry on the part of the author of these two constructions and an extraordinary sensitivity to ensure that the entire work harmonies.

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