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The Aesthetic Geometry of Holy Places: A Case Study of Intrinsic Relations through Traces

Estetyczna geometria miejsc świętych – wewnętrzne relacje poprzez odwzorowania

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Słowa kluczowe: proporcje architektoniczne, dziedzictwo, kościół, odwzorowania, relacje modularne, geometria, pomiary, badania architektoniczne, architektura gotycka, estetyka gotycka, Santos Juanes (Walencja, Hiszpania)

Introduction

Heritage of such importance as that of the Santos Juanes Church in Valencia, Spain, awakens a myriad of questions jealously hidden behind the masonry of a building with more than 700 years of history.

The building, located in the Ciutat Vella district, is one of the most important religious spaces in the city. However, when entering its interior, the last thing imagined is that the building was erected according to pre-established geometric relations in both plan and elevation terms. Merely contemplating its architectural space does not suffice to intuit the existence of the mathematical reason behind the building's constructive "magister operis."[1]

For this reason, and without leaving aside the other peculiarities that have occurred to the building, which largely define its current personality, this work aims to explore the features defining its character, configuration and aesthetics. These features were the basis of its construction, and are fundamental to undertake any heritage intervention today.

In order to examine the harmonic relations between the different compositional elements that make up the architectural space, and beyond a simple visual analysis, a study based on the planimetric drawings of the building is much more appropriate. However, this is not a matter of the drawings and layouts, as we understand them today, rather representations of the plan and elevation of the fundamental parts required for construction.

Therefore, given the widespread nature of the compositional solution chosen, and used in the Santos Juanes Church and other contemporary works, this work aims to analyze the geometric relations on which the construction of this church was based. This research work was carried out by measuring the building itself, reading the construction principles, and establishing the thresholds that rationalized them and guided the construction process.

However, this work would not have been possible without the help of the research works conducted by prestigious scholars of medieval design: a design based entirely on drawing, as a fundamental tool in the build-

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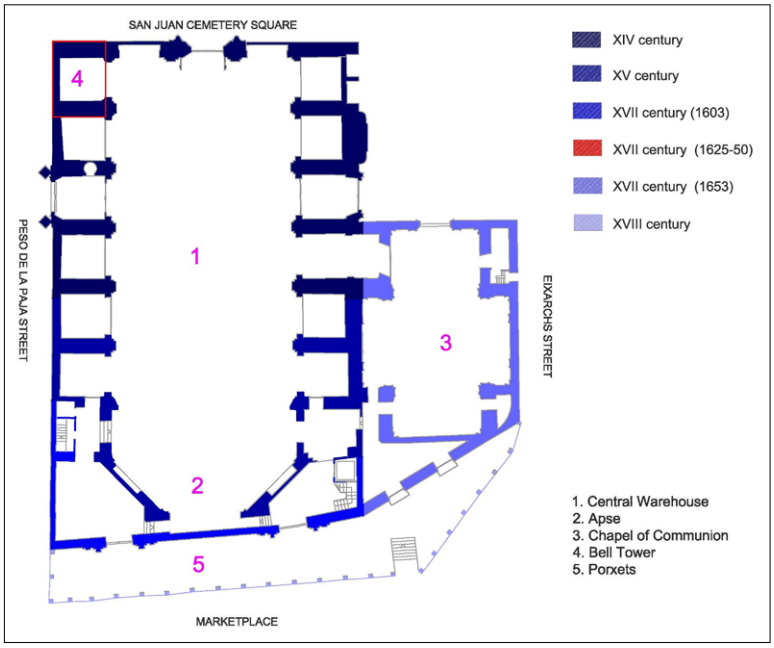

Fig. 1. Santos Juanes Church, floor plan with wall layers in chronological order (upper legend); and descriptions of distinctive structural elements (bottom legend); by the authors.
Ryc. 1. Kościół Santos Juanes: rzut z warstwami ścian w porządku chronologicznym (górna legenda), opisy charakterystycznych elementów konstrukcyjnych (dolna legenda); oprac. autorzy.

ing's compositional ideation process, which shapes the building's aesthetics, as we know it today.

The church's historic-constructive evolution

The history of the Santos Juanes Church in Valencia is long. The original church was founded during Reconquest period outside the city's walled enclosure and next to one of the gates to the city, La Boatella. However, this original hermitage was burnt down in 1311, when building the new church on the site where the church we know stands today was decided. This new construction was built in line with the Catalan Gothic style with a single nave and a magnificent, large light vault. At this time, and as Galarza reported, the floor plan consisted of five modules and a straight apse without a front door or a communion chapel.[2] The adopted solution was typical of the churches of that period. Figure 1 shows the chronological evolution of the church's construction.

In 1592, as indicated by Gil Gay in the book *Memories of the Vicaria*, the church suffered a second fire that completely destroyed the front of the church.[3] This fact would not only involve the rehabilitation of damaged parts, but also the enormous rebuilding and transformation of the church. The original building was extended by one module and a hexagonal apse was added to the posterior facade. Moreover, this intervention was also characterized by the emergence of a new artistic trend: the Baroque. Its influence led to most churches being completely transformed by adapting the initial Gothic complex to the aesthetics of that time. At the Santos Juanes Church in Valencia, this fact left the Gothic ensemble barely visible on the outside because it was very much hidden inside.

Of the first exterior transformations that the church underwent to adapt it to the new style, we highlight the construction of the facade over the Market Square. At that time, this facade hardly featured any ornamentation. This new element was built to open up and show the presence of the church to an urban environment dominated by the Lonja (Silk Exchange) since its construction in the fifteenth century. For this reason, and given its lack of functionality, and its meaningless accesses service spaces, and this element was created for the sole purpose of showing and maintaining the importance that Santos Juanes had until that time in the aforementioned square and its neighborhood.

In the seventeenth century, the last body was added to the building: the Communion Chapel (Fig. 1). Its construction focused on the construction treaties of that time, guidelines that came about to solve specific construction problems, such as damp and humidity, and the proposed measures to solve them. It was built between 1644 and 1653 after expropriating several annexed houses.[4] This represented a significant change in the proportions that had been maintained since the times of the original church.[5] For this reason, this volume is not included in this analysis. Also in the seventeenth century, the body of the bell tower was built over the original lateral chapel. A Baroque vault was also built at this time in the central nave, in addition to the ones in the side chapels that obscured the original Gothic structure. Finally, the *porxets*, or porches, were built.

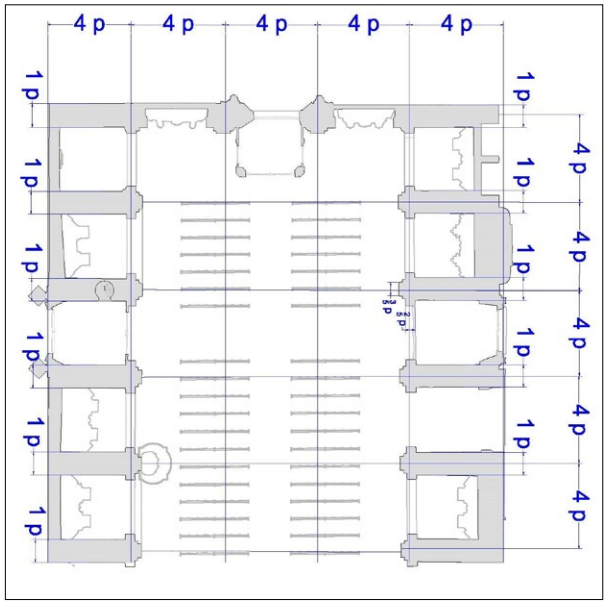

Fig. 2. Modulation of the Santos Juanes Church's original plan; by the authors.
Ryc. 2. Modulacja pierwotnego rzutu kościoła Santos Juanes; oprac. autorzy.

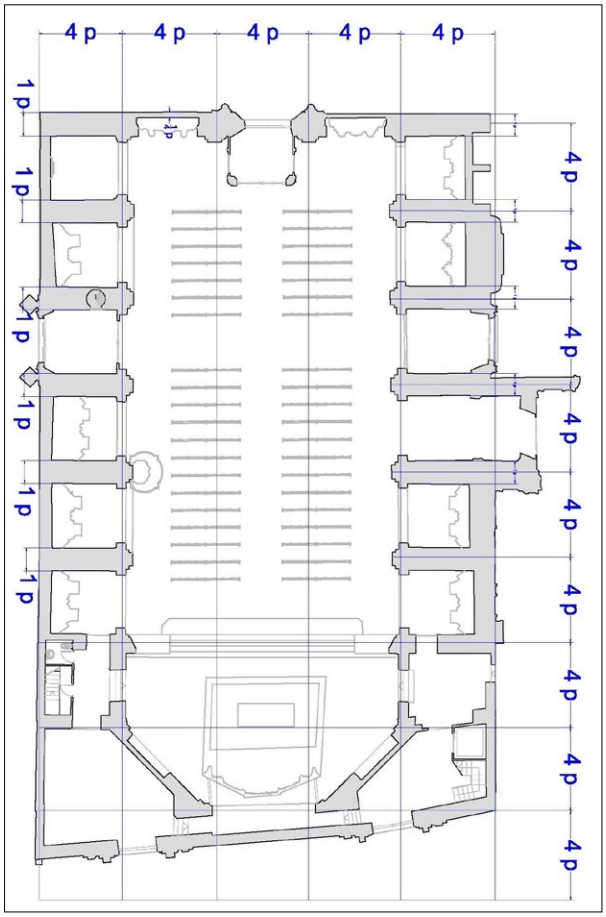

Fig. 3. Modulation of the current main Santos Juanes Church body; by the authors.
Ryc. 3. Modulacja stanu współczesnego głównej bryły kościoła Santos Juanes; oprac. autorzy.

Composition and architectural measurements

The difficulty in obtaining the original Santos Juanes Church traces, as in other cases, is preceded by two facts: lack of knowledge about the architect because no documents exist; and the many changes that it has undergone.[6] However, thanks to the obtained graphic documentation and the building's construction analysis, we carried out a study of the building's traces. This analysis allowed us to obtain the traces used to construct the church, and to gain insight into its intrinsic properties, which are of vital importance to understand its aesthetics and its current *raison d'être*. The study was conducted according to the following working hypotheses: directly measuring the building itself, reading the construction principles, and having to establish thresholds that rationalize them and that had guided the execution process.

The study of the traces focused on defining the original building design that the master builder or architect had followed.[7] To this end, this work considered the compositional and spatial organizational schemes of the geometric system in the proportions assumedly used. In addition, it took into account the intrinsic geometric shapes that defined its origin.[8] In this way, the used method followed the guidelines set by the historic context of that period, which was essential for establishing the architectural reasons applied by the master builder. Then we applied the same resources that were used and adopted in the established compositional processes of that time.[9]

The process involved searching for the traces that defined the church based on studying treatises, together with analyzing the geometric figures applicable to the obtained graphic documentation that, in this case, came from a laser scan of the building. In this way, the method focused on the guidelines set by the most important ancient and medieval treatises. The interpretation of one of the most important treatises in architecture, Vitruvius' treatise, was fundamental.[10] Vitruvius reflected the fundamental principles of constructions of ancient times. Based on this, the present work sought the common premises of the Santos Juanes Church with the guidelines proposed in it by comparing them to other similar studies performed in churches and basilicas.

Vitruvius's treatise collected and analyzed the architectural concepts of the theory of proportion, which served as a guide in this research work; e.g.: *ordinatio*, *dispositio*, *symmetria*, *eurythmia*, and *decor*.[11] These criteria marked the analysis and justified its conclusions. For this reason, the description of each concept proposed by Vitruvius was essential to understanding the analysis. The first of these, *ordinatio*, refers to the search for the right size, construction based on a specific modulation that facilitates the temple's architectural development by offering canons of the correct proportion between different building parts.

Compositio. Although it was not explicitly mentioned in the treatise, it is constantly referred to in several of its books about the search for the proportion of architectural pieces. Accordingly, Vitruvius proposed taking

a module from the base of the temple as a reference to serve as the basis for the temple's composition.[12]

"Composition arises from symmetry and this from the proportion of reason (quotient)."[13]

Vitruvius defined *dispositio* as the set of ideas based on the geometric explanations and reasons that determine a building's intrinsic relations, understood as a project. Similarly, he defined *eurythmia* as follows: "*Eurythmia* is the beautiful and pleasant aspect that results from the arrangement of all the parts of the work, such as the correspondence between height and width and length so that the whole has the proper proportions."[14]

As its name suggests, *decor* is translated as the adaptation of form to function, understood as that which follows the customs of the construction site.

The different concepts presented by Vitruvius define some of the characteristic guidelines of constructions of that time. These terms, which he analyzed in his books, allowed us to gain insight into and understand the reasons behind the constructive solutions of many historic heritage buildings that we know today.[15] Therefore, based on these established guidelines, the research in this work focused on two clearly marked lines: studying the measurement system and studying the temple's geometric system. The aim was to obtain as much data as possible about its construction relations in an attempt to discern the reasons for its origin by highlighting the initial premises that shaped the temple, which should be the basis for future interventions.

Studying the measurement system

Before beginning a more detailed study of the church's measurements, a more specific analysis of the systems used at the time it was constructed was performed. To do so, we had to go back to the fourteenth century when, according to all the hypotheses, construction on the church began. In this century and later, and mainly because available means were scarce, a different measurement system was applied to the current one. Consequently, the first proposition was to know the followed system according to the location, specifically in the area where the church is located in Valencia (Spain).

The measurements taken mainly as a basis for constructions during this period did not date to the fourteenth century; instead these systems had been used since the times of the Roman Empire. Their evolution was constant and resulted in many variants depending on geographical location.[16] Although different procedures were followed, there were similarities between them. The importance of the location of the applied system should be emphasized. In Valencia, the measurement system set at that time, used as a reference for construction, was *vara* or *alna*, *palmo* and *codo*. The characteristics of these measurements had certain limitations and, consequently, they could not be used for large-scale measurements, such as air, land and sea, which had a different measurement system. However, it is not relevant for this work.

Table 1 shows the most significant measures applied at the time the Santos Juanes Church was built and their current equivalence.[17]

Table 1. The units of measurement used in Valencia and their equivalents in the international metric system, by the authors.

Unit of measurement	Equivalent	
Valencian Vara	0.91 m	3 feet = 4 Valencian palmos
Pie (foot)	0.30 m	1/3 Vara
Valencian palmo (span)	0.23 m	1/4 Vara
Codo (ell)	0.45 m	

Knowing these equivalences, and according to the graphic documentation of the laser scan carried out inside the temple, their correspondence to the existing reality in the Santos Juanes Church was analyzed.[18] To modulate the temple's traces, researchers accepted a maximum 1% error and not exceeding 10 cm. A tolerable error of 5 mm was considered for those lower than this 1%.

Based on this, and to make the study as complete as possible, a decision was made to carry out a measurement study of two different plans: an original first plan and the current plan that has undergone modifications and extensions. For this approach, it was essential to analyze the layout corresponding to the original one (Fig. 2), and to subsequently study the current plan to find out its possible subsequent evolution. For this reason, and to gain a better understanding of the measurement system applied, Vitruvius's contributions had to be applied again. In them, he affirmed that the module to obtain the ground plan traces must equal the diameter of the column of the temple's central structure, and its height will depend on the building's intercolumniation.

At the Santos Juanes Church, the plan follows a clear modulation of four spans.[19] Its module is the equivalent to 1.38 m in the current metric system. It corresponds to the construction base of the longitudinal and transversal design of the lateral chapels. This module is repeated five times in both length and width to form the central nave and to define what is considered to be the church's first layout. This confirms that the module repeated in the original plan coincided with the column's diameter, as Vitruvius pointed out, to seek symmetry in both directions.

In order to check whether the subsequent building extensions faithfully followed the original modulation, the researchers repeated this module on the current floor plan. For the first extension of the plan carried out years later, the module in the original one was used to build it (see Fig. 3). The last side chapel and the hexagonal apse that we know today were built as a part of this extension.

On the contrary, the subsequent extensions did not follow a fixed pattern. These include the construction of the facade over Market Street, which was added centuries later. Maintaining the established

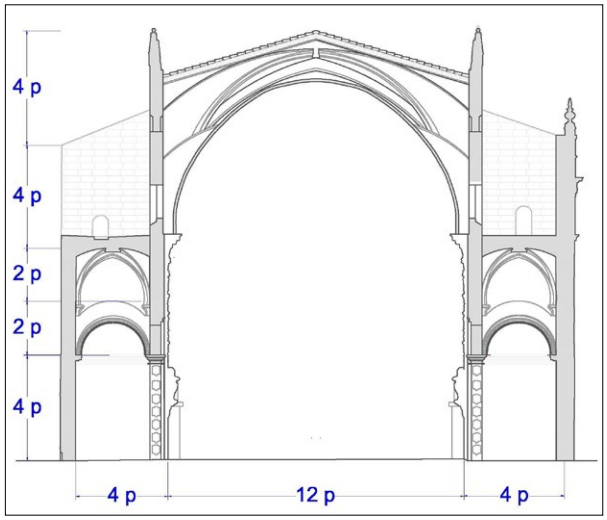

Fig. 4. Cross-section of the Santos Juanes Church displaying modular relations; by the authors.
Ryc. 4. Przekrój kościoła Santos Juanes przedstawiający relacje modularne; oprac. autorzy.

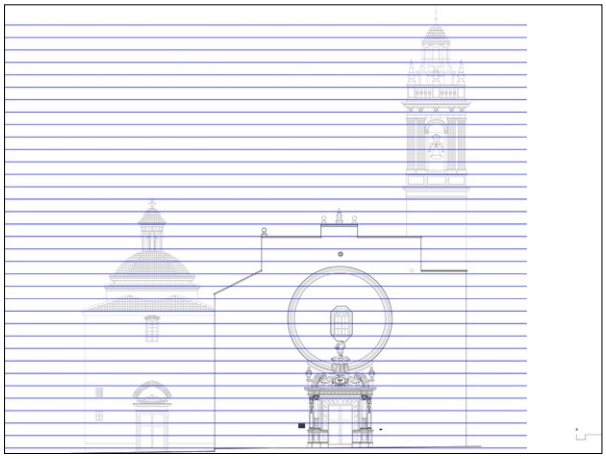

Fig. 5. Modulation of the elevation facing the San Juan Cemetery Square; below: modulation detail in the walled rose window; by the authors.
Ryc. 5. Modulacja elewacji od strony placu Cmentarza San Juan, poniżej: modulacja detali w rozecie; oprac. autorzy.

modulation was not a concern, but highlighting its urban character and its presence in the square was. Similarly, the Communion Chapel, which was the result of purchasing adjoining houses/dwellings, does not match any pattern with the original one. This is due to the concern for isolating the building from the other blocks rather than following the planned growth patterns. Thus, the modulation is located on the longitudinal facades and the front wall of the apse if we consider that this perimeter corresponds to the original building and its first extension built some years later. This area corresponds consistently with the Gothic part of the church.

However, according to Vitruvius, not only does the plan have to comply with the premises set out in proportion and symmetry terms, but also the cross-section has to clearly correspond to it. The same modules reflect this correlation in the section system of the ground plan employed (Fig. 4). The first module (4 p) marks the beginning of the arches in the lateral chapels. At that time, they firstly showed Baroque arches, and not the original Gothic ones. Hence, it is interesting to note that these arches comply with the modulation set out so far in advance of their construction. This fact denotes the importance of this construction system and how, in later interventions, it was taken advantage of, by respecting them as much as possible, and maintaining them even at completely different times three centuries later.

The second module is drawn in two parts to improve its understanding. This is due to the interest in highlighting two clearly modulated parts. On the one hand, the first half defines the start of the Gothic arches of the chapels and (2 p), on the other hand, the second half coincides with the keystone or the highest arch point (2 p). The last two upper modules of the section also reflect important information. The third indicates the height of buttresses, and the last denotes the church's total height in the central nave. Both have a modulation of 4 spans (4 p).

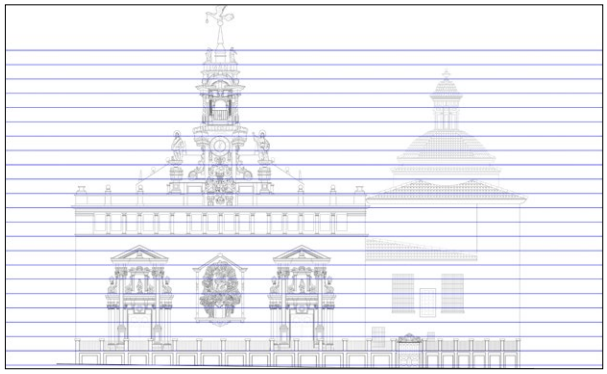

Fig. 6. Modulation of the elevation facing the Market Square; by the authors.
Ryc. 6. Modulacja elewacji od strony rynku; oprac. autorzy.

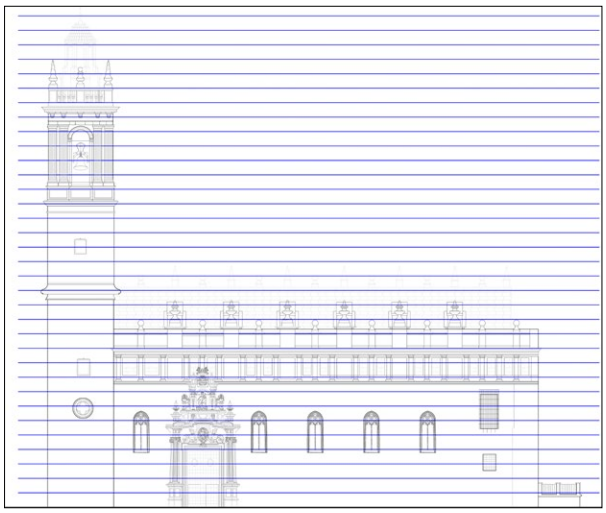

Fig. 7. Modulation of the elevation facing Calle del Peso de la Paja; by the authors.
Fig. 7. Modulacja elewacji od strony Calle del Peso de la Paja; oprac. autorzy.

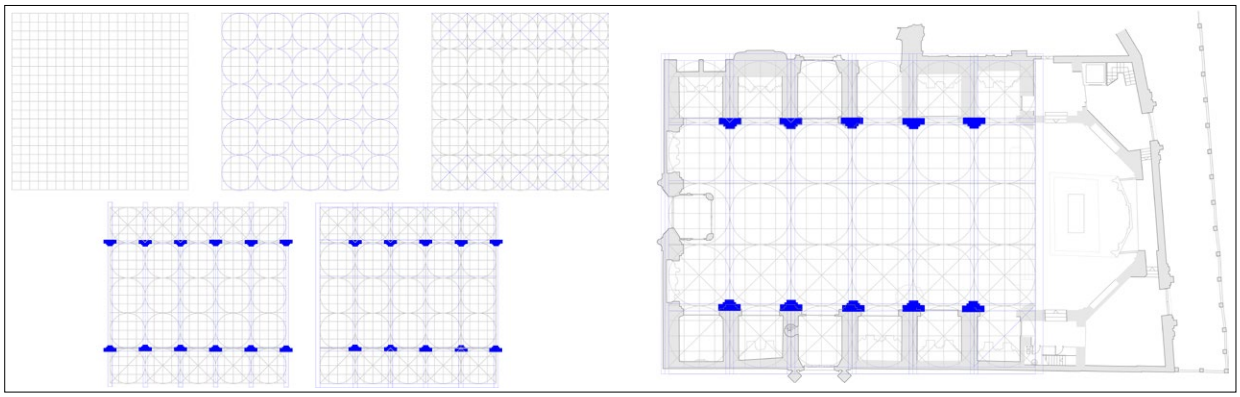

Fig. 8. M steps proposed to obtain the geometric layout; by the authors.
Ryc. 8. M kroków mających odtworzyć układ geometryczny; oprac. autorzy.

It is also interesting to study elevations to search for the unity of the architectural ensemble. Of them, the elevation of the facade facing the San Juan Cemetery Square, located at the foot of the church, is that which has undergone the fewest interventions throughout its history. So it perfectly complies with the established modular grid of 1 Valencian span, i.e., 1 p (see Fig. 5). We highlighted the height of the door, the lintel, the window where the famous Santos Juanes "O" is (a walled rose window),[20] the total facade height and, surprisingly, the height of the bell tower, whose construction is dated to after the original structure. Also shown in figure 5 is the walled rose window, which also follows the 1 p modular grid, with a total height of 8 Valencian spans (8 p).

Similarly, the elevation facing the Market Square (Fig. 6), located at the head of the church, once again follows the pre-established constructive modularity. Once more, it marks most of the heights of the key elevation points but, as discussed in Section 2, this was done later.

The same operation was repeated in the two remaining elevations. However, unlike the previous ones, these two elevations have undergone the most modifications throughout the church's history. That corresponding to the Communion Chapel was built later and, given its sobriety, did not allow any clear conclusions to be reached. It is impossible to state when it was built exactly, and whether the master builder applied the pattern that is followed throughout the temple.

Despite undergoing numerous modifications, in the elevation facing Calle del Peso de la Paja (shown in Fig. 7), the height of the facade, the door, and that of the most important parts of the bell tower, all coincide with the proposed modulation. Once again, the results showed the importance of the grid, which was even respected in later constructions.

Geometric study

Having verified the existence of a measurement system, this section aims to develop the binding geometric system that was taken into account in both the conception and execution of the building. Authors from this period felt that this system was more successful, and more accurate than the metric one. This is because the system relies on some known basic figures, which facilitate the unification of criteria and allow disparate measurements to be ruled out according to the geographical location where the temple was built.

The procedure focuses on obtaining a regulatory layout based on composition and design through easily describable architectural figures. Its application provides the location of the singular points and its layout of the temple. The most frequent shapes are defined by simple figures, such as square, circle, triangle, etc. Employing simple instruments, which were the only ones available at the time, facilitated using this elementary configuration to trace or measure them. Of these, we find measuring stick, square, compass and surveyor's chain, of which the last one was employed to define rooms.

Of all the architectural figures, square is considered to be the most important form, and cube or hexahedron derives from it. When these last two figures overlap the circle, the ratio between their diameters defines wall thickness or the area of interior spaces. It consists of intentional and logical beauty, in addition to the practicality that its implementation offers as it can be easily drawn with a string or compass. The circle and arches of the circle, used mainly for the formation of the ribbed vaults and ornamentation, are drawn based on previous ones, and are one of the most widely used figures.[21]

However, the main advantage of this system is the ease with which simple geometric figures could be dealt with without having to possess extensive mathematical and drawing knowledge. It is a much simpler method than the metric one and is perfectly applicable as a basis for laying out and constructing the church. Consequently, a detailed study of the ground plan was carried out by checking the geometric relation of the different parts of its layout to the basic proposed figures. As in the previous case, we first analyzed the ground plan and then examined the section to extract as much information as possible about the construction guidelines

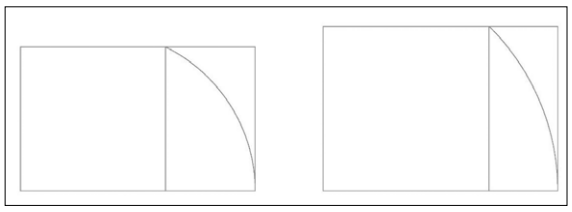

Fig. 9. Representation of the auron and the diagon; by the authors.
Ryc. 9. Przedstawienie auronu i diagonu; oprac. autorzy.

that were followed to build the church. Figure 8 shows the hypothesis put forward about the possible geometric traces, which could have been carried out to design the ground plan of the Santos Juanes Church. It shows the steps followed during its evolution until the overall layout was obtained.[22]

This study was only done on the original church floor, which responds to the original temple layout. However as the measurement analysis showed, the church faithfully follows this regulatory layout up to the apse, which was added a few years later during the first extension. Therefore, the geometric study was carried out using a grid with the module obtained from the measurement study. This led us to think that the first layout could have been done on a square, typical of Reconquest churches, and could correspond to the ratio of √2.

The second layout corresponds to the layout of a series of circles that are circumscribed within 25 squares. This responds to a modulus of five by five. If the diagonals are drawn in the respective squares, they delimit the side chapels. In addition, the meeting points of the diagonals mark the central point of the axis of the main structure's pilasters. Similarly, the band corresponding to the church pillars coincides with the outer façade limit by outwardly tracing a module. Finally, the layout overlaps the general plan to include all the steps carried out in a single hypothesis.

Having obtained the general lines that would define the hypothetical geometric layout in the plan, and to verify the relation of the patterns followed throughout the building as a whole, all that remained was to analyze their correspondence in the elevation. To establish the bases that could form it, the harmonic development of the base geometry had to be known, as shown in Figure 9: the *auron* and the *diagon*.[23]

With these geometric patterns, and given the basis of the layout of most churches from that period, this research work verified their coincidence with the Santos Juanes Church. Figure 10 shows a section in which the *diagon* and the *auron* coincide with the temple's central nave width. The height of the *diagon* defines the start of the Gothic arches of the central nave and the *auron* defines the keystone of the Gothic structure of the chapels. In addition, if three circles with the same diameter as the plan's traces are arranged on the plane that defines the *diagon*, the tangent point between the central one and the two lateral ones marks the center of the arch that defines the pointed shape of the sash arches (barrel arches).

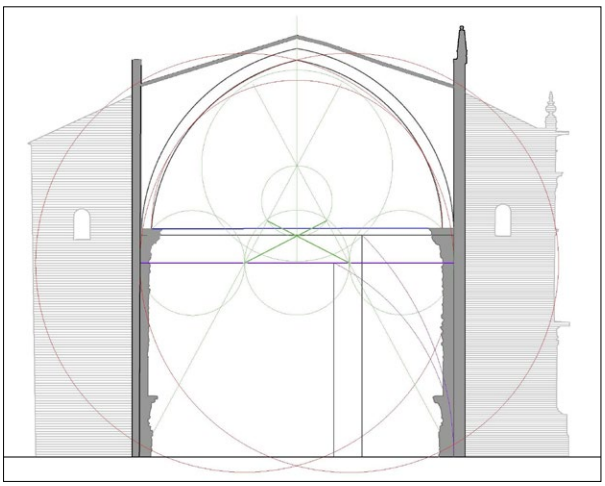

Fig. 10. Geometric cross-section of the Santos Juanes Church; by the authors.
Ryc. 10. Przekrój geometryczny kościoła Santos Juanes; oprac. autorzy.

However, the current church view hides this original main nave structure under a Baroque vault. To build this Baroque vault, the original Gothic structure was used by anchoring it to the sash arches and resolving the upper meeting with an oval shape. Once again, the original geometric system was used as a basis for finishing the baroque vault. To execute the oval shape of the upper finish, the point that resulted from the intersection of the diagonals that originated at the central nave ends, by passing through the tangent of these first three defined circles, was utilized. In turn, these diagonals were in charge of defining the two points of tangency of the original layout with the baroque oval finish.

Finally, both the measurement and geometric study reflect the search for common proportions throughout the building to achieve a common whole through the temple's traces. In both systems, there is a latent concern to find and indicate the critical and important points based on an established pattern by bearing in mind the five premises established by Vitruvius to achieve highly desired beauty.

From the constructive point of view, this analysis showed the existence of an original, clear layout, composed of a 5x5 modulation, which corroborated the premises set out in Section 2. However, it also demonstrated that the first extension followed the same growth pattern as the original building, at least up to the apse, which denotes the relevance of these systems as the basis for correctly executing the buildings of that period. To a certain extent, the Baroque transformation also centered the layout and position of the new churches' singular points on these geometric patterns.

Conclusions

By taking the Santos Juanes Church in Valencia, Spain, as an example, whose construction was carried out during the Gothic period, this work shows a methodolo-

gy to study the traces and proportions of temples. The proposed methodology considers that the preserved information on this regard is practically non-existent. For this reason, the researchers propose a systematic method of analyzing traces by two studies: the measurement system of the temple and the geometric system of traces.

The measurement study defines the proportion and area of the original plan by corroborating that it fulfils the hypotheses set out at the beginning. In this way, it is possible to verify the symmetric modulation in both directions, defined as spans, whose pattern coincides with the width of columns as indicated by Vitruvius. It also verifies that the first church extension was built based on the original modulation. Thanks to this, its scope can be determined, which includes the construction of another identical module to previous ones and walls delimiting the apse.

Furthermore, this research corroborates a direct relation in terms of the measurements of the ground plan, the section and elevations. It verifies that the pattern established for the plan vertically defines the most important points of the church: the start and keystone of the Gothic arches of the lateral chapels, the height of the buttress, and the total church height. In the section, the height of doors and the total facade height; in elevations, the most relevant parts of the bell tower.

Geometrically, the church follows the guidelines established for other Reconquest churches. Thus, its ground plan perfectly defines the shape and dimensions of the central nave and side chapels. Likewise, it verifies that the temple's section has a geometric relation in defining the elements composing it. The *auron* and the *diagon* mainly define the start of the transverse arches and the center of their layout. The application of modern technologies will allow the formulation of precise research hypotheses and a more in-depth understanding of historical construction techniques. This study can serve as a confirmation of the mastery of historical masters.[24]

These conclusions demonstrate the vast importance of these systems for construction projects at that time, to the extent of them acting as a basis for later extensions or transformations, which is what occurred at the Santos Juanes Church in Valencia. In this way, these studies prove their correspondence with the construction elements executed during the Baroque period, such as the vaults of side chapels and the upper oval top of the central vault.

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Abstract

The Santos Juanes Church in Valencia, Spain, is one of the most important religious buildings in the city. Based on this church, this work proposes an analysis that can be extrapolated to other historic buildings where, like this one, no detailed documents on constructive measurement reasons exist. Hence the present work outlines the unpublished hypothesis of how the sequential process of traces on both the plan and section might have been based on the different ancient and medieval architectural treatises. All this will allow the existing intrinsic relations between the shape of the building and its current aesthetics to be obtained through a metric and geometric analysis of the church.

Streszczenie

Kościół Santos Juanes w Walencji jest jednym z najważniejszych budynków sakralnych miasta. Na podstawie tej świątyni artykuł proponuje analizę, która może być przeniesiona na inne budynki historyczne, nieposiadające – podobnie jak ona – szczegółowej dokumentacji dotyczącej wymiarów konstrukcyjnych. W związku z tym tekst przedstawia niepublikowaną hipotezę odnośnie do sekwencyjnego rozmierzania zarówno rzutu, jak i przekroju, które mogło być oparte na różnych starożytnych i średniowiecznych traktatach. Wszystko to pozwoli ustalić relacje pomiędzy kształtem budynku i jego obecną estetyką poprzez metryczną i geometryczną analizę kościoła.