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ARTICLE / ARTIGO

Architectural analysis of the main facade of the collegiate church of Osuna using high-density data collection

Análise arquitetónica da fachada principal da igreja colegiada de Osuna através da recolha de dados de alta densidade

FERNANDO DÍAZ-MORENO
EDUARDO ACOSTA ALMEDA*

Architectural Graphic Expression Department, High Technical School of Architecture, University of Seville, Av. Reina Mercedes, 2, 41012, Seville, Spain

**eduacosta@us.es*

Abstract

This study examines the collegiate church of Nuestra Señora de la Asunción in Osuna, Spain, begun in the early 16th century. It presents numerous geometric alterations and a strong material heterogeneity, making it difficult to understand the construction sequence, and thus its heritage value for possible restoration work. The study aims to determine whether these anomalies are original or the result of later interventions. We therefore analyze both the structural and geometric details of the facade panels, approaching the subject from multiple perspectives thanks to the methodological improvements on the field of heritage building survey. The analysis of mass data collection suggests that geometric deviations are due to issues that emerged in the set-out survey for the building works, and that the facade was constructed in a continuous phase during the 1530s. The study concludes that the facade likely originates from the workshop of master Diego de Riaño.

KEYWORDS
Renaissance architecture
Photogrammetry
LiDAR
Point cloud data analysis
History of construction
Diego de Riaño

Resumo

Este estudo analisa a igreja colegiada de Nuestra Señora de la Asunción em Osuna, Espanha, iniciada no princípio do século XVI. A fachada apresenta muitas alterações geométricas e heterogeneidade material, dificultando a compreensão da sequência construtiva e, consequentemente, o seu valor patrimonial para eventuais intervenções de restauro. O estudo tem como objetivo determinar se estas anomalias são originais ou resultado de intervenções posteriores. Por isso, analisamos os pormenores estruturais e geométricos dos painéis da fachada, abordando o assunto de múltiplas perspetivas graças às melhorias metodológicas no campo do levantamento do património edificado. A análise da recolha de dados em massa sugere que os desvios geométricos da fachada se devem a questões que surgiram durante o levantamento das obras de construção e que a fachada foi construída numa fase contínua durante a década de 1530. O estudo conclui que a fachada é provavelmente originária da oficina do mestre Diego de Riaño.

PALAVRAS-CHAVE
Arquitetura renascentista
Fotogrametria
LiDAR
Análise de dados de nuvens de pontos
História da construção
Diego de Riaño

Introduction

The Renaissance collegiate church for the town of Osuna (c. 1531-1537) was a complex intervention financed by the fourth Count of Ureña (Figure 1). It is one of the essential buildings for understanding the transition from Late Gothic to Renaissance in Western Andalucia and, by extension, in the kingdom of Spain. The remit of the national Research and Development (R&D) project *Master Diego de Riaño and his stonemasonry workshop: Architecture and ornament in the context of the transition to the Renaissance in southern Europe* includes a complete study of the church; the work described here forms part of that project.

The facade presented an impediment for the definition and appreciation of the sixteenth-century design, primarily because the existence of significant geometric distortions and a puzzling material heterogeneity made it difficult to conduct a thorough analysis.

To conduct a rigorous analysis of the collegiate church facade, we used high-resolution orthophotos obtained with a laser scanner and drone photogrammetry to study the wall surfaces. As a supplementary source we used the information provided by the high-density point cloud. The result is twofold: an unprecedented reasoned sequence of the construction of the facade, which we ascribe to the design of Diego de Riaño; and a tested methodology that will improve the analysis and representation of heritage buildings using high-density data collection.

Figure 1. Plan of the town of Osuna and southwest view of the collegiate church.

The conclusion of these analyses is that the main facade of the church corresponds to a continuous construction process, associated with a single construction unit that would include the pillars, walls and vaults of the main nave and side aisles. Therefore, its execution is related to the design of the collegiate church of the second third of the sixteenth century.

It is important to emphasize that the result of the study allows us to accurately date the materiality of the facade of the temple, serving as a starting point for an adequate patrimonial interpretation for future restorations. All of it should be considered as a result of the Renaissance project and, therefore, of great architectural value and worthy of being preserved as far as possible.

Case study

In 1531 Juan Téllez-Girón succeeded his brother as the fourth Count of Ureña and Lord of Osuna. The new count was a generous patron of religious works, founding and funding numerous churches and monasteries throughout his large domain [1]. He paid particular attention to Osuna, where the collegiate church represents his most outstanding work.

Charting the history of this building is a complex task due to the lack of information and the numerous interventions that have distorted the original design. We know that the site on which it stands was once occupied by a parish church, the only one in Osuna [1], and that in 1526 the construction of a new chancel was under way [2]. A few years later, the fourth count embarked on an ambitious project to turn the parish church into a collegiate church. This gave rise to an entirely new nave-and-aisle section, likely respecting the existing apse and tower (Figure 2). As the only parish church in the town, religious services would have been conducted in the apse while the new section was being built. This apse must have been completed in 1534 because the flooring was laid and artworks were installed that year [1]. The building works commenced around 1531 and, soon after, the date 1533 was engraved on the main church portal. The project for collegiate church was likely initiated before official permission was received, because this only arrived in 1534 with publication of the papal bull for the creation of the institution [3]. Although we do not know for sure who authored the design, new data point to Diego de Riaño [4].

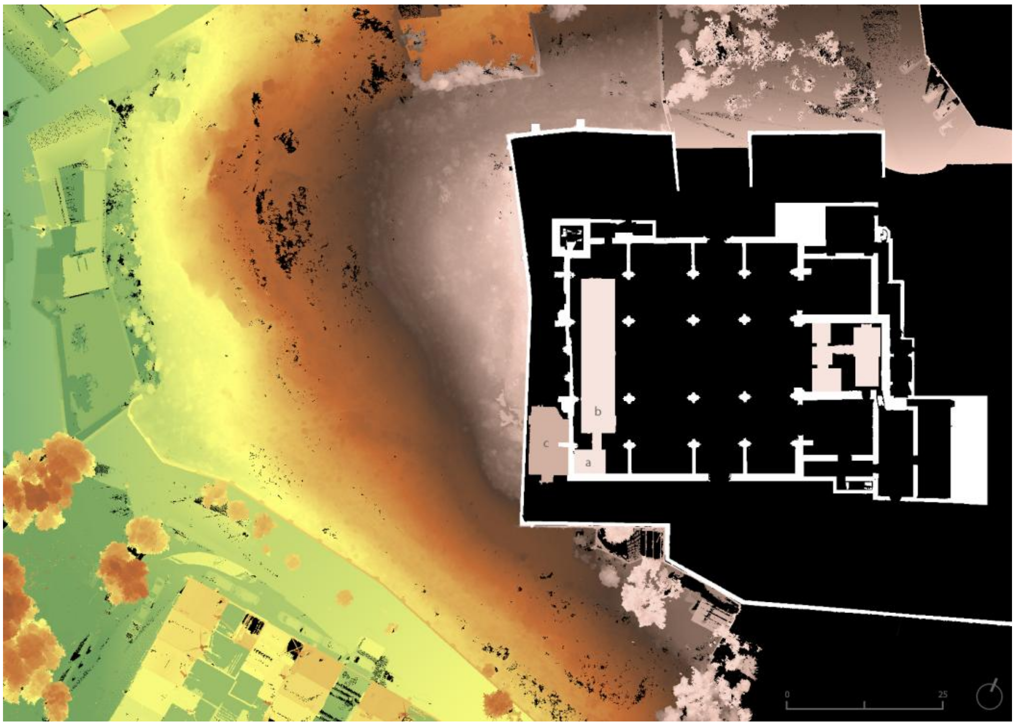

Figure 2. Point cloud horizontal cross section through the crypts with Digital Surface Model of the surroundings: *a)* crypt under the Chapel of the Kings; *b)* 1797 crypt; *c)* cryptoportico.

The collegiate facade represents an enigma in the original design. It faces west and stands on a raised atrium that compensates for the uneven terrain (Figure 1 and Figure 2). Today, the main facade opens on to waste ground, formerly the site of medieval Osuna that was abandoned and demolished after the townsfolk gradually moved outside the walled [5]. In addition to the accesses to the atrium via the side facades, a (now lost) stairway led directly up to the main entrance [6].

The facade is 20 meters high and 40 meters wide (Figure 3). It has four exposed buttresses and two stairwells that rise from the church floor to the roofs over the nave and aisles. There are three portals: the main one or *Puerta del Sol*, and two smaller ones that were walled up in 1798 [7].

A cryptoportico covered by two vaults was built under the atrium, taking advantage of the difference in ground level at the south-west corner (Figure 3). This space, currently accessed through the crypt near the church entrance, seems to have served as an extension to the funerary crypt and, more recently, as a storeroom.

The facade has undergone several interventions due to various traumatic events. For example, in 1918 the tower collapsed, possibly due to its structural weakness [7], as it was built with walls formed by exterior ashlars of "very inferior limestone" and by a "filling of rubble without any binding" [8]. Also, the facade foundations subsided when a crypt was excavated near the church entrance [8]. As a reinforcement mechanism, that same year the window over the main portal was bricked up [8-9].

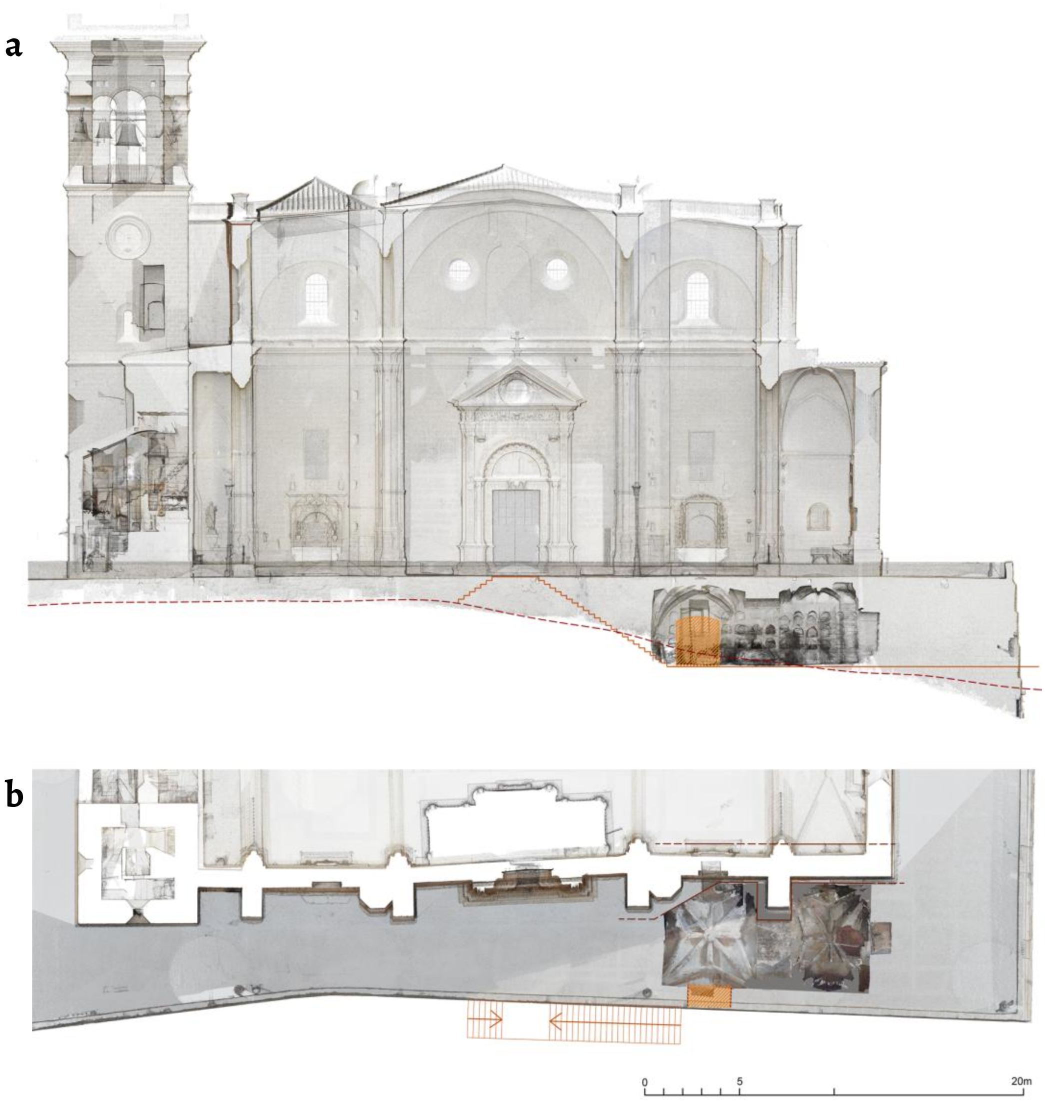

Figure 3. Facade with cryptoportico and possible stairway: *a)* floor plan; *b)* elevated plan.

Other transformations add even more challenges to our understanding of this elevation: the damage caused by Napoleon's troops during the French occupation [1], the mortar cladding over the entire interior elevation and the repairs to joints and ashlars in the lower part of the facade [10].

Lastly, the main elevation presents erosion issues due to the action of the sun and wind, areas of biological colonization and dirt, etc.

Research aim

The main aim of this study is to elucidate the building sequence of the facade and, by extension, contribute new data about the development of the overall church design for future conservation works.

The analysis of the aforementioned geometric distortions and material heterogeneity visible on the facade, which we undertook as a necessary step to determine how the execution of this part of the church fits in with the overall building process, prompted us to conduct a detailed study of the facade surfaces. That task required extending our research to the section of the atrium in front of the facade and the semi-underground cryptoportico (Figure 3), both of which were likely built at the same time as the facade.

Meanwhile, the continuous development of data collection devices, which tend to increase both the volume and typological diversity of the data collected, coupled with the improvement of data management software, should lead to changes in the methodology we use to analyze these data. This article explores the application of these advances to the study and representation of heritage architecture.

Materials and methods

As our first step, we created a cognitive corpus that allowed us to formulate an initial hypothesis about the construction of the building, which in turn enabled us to establish the aims of the following stages [11]. Next, we laser scanned the collegiate church and urban vicinity. For this task we used a Riegl Vz-400i scanner (Table 1) with a Nikon camera (Table 2) for coloring the point cloud. However, for the narrow space of the crypts we used a smaller and lighter scanner, a Leica BLK360 (Table 1).

We opted for photogrammetry to generate the orthoimages of the facade used to study the wall panels. Due to the height of the elevation and the narrow dimensions of the atrium, we decided to use aerial photographs with a DJI Mavic 2 Pro (Table 2). As the most restrictive data item, we established the minimum safe distance between the drone and the wall (proximity sensors activated) and obviated the GSD (< 0.05 cm/pix). We obtained this value by calculating the overlapping distance between captures.

The next step was to process the 600 photographs with Agisoft Metashape 1.5. To ensure the correct geometry and orientation of the photogrammetry point cloud it was necessary to introduce control points in the cloud [12]. For this purpose, we opted for circular coded markers that had been uniformly placed on the surface of the facade prior to data collection (Figure 4a). We collected these markers with the scanner to obtain their geographic coordinates. Once they were entered into Agisoft Metashape – the program recognizes them automatically, we obtained a total error of less than one pixel and less than three millimeters.

To optimize the point clouds and reduce the tie point errors, we followed the recommendations of Mayer, Gomes Pereira and Kersten [13]. We compared the two point clouds: the one from the scanner has a higher density, only in the lower areas of the facade, but greater heterogeneity in the whole (Figure 4b-1), while the photogrammetry cloud has a lower but more constant density of points (Figure 4b-2).

Table 1. Scanner specifications.

Model	Type	Range measurement performance			Scan pattern				
		Wavelength	**Max. range**	**Min. range**	**Measures**	**Resolution at 20m**	**Registration**	**GNSS Receiver**	**Weight**
RIEGL VZ-400i	Pulsed ToF	Near infrared	250 m	0.5 m	500.000 pts/s	7 mm	After acquisition	GPS	9600 g
Leica BLK360	Pulsed ToF	830 nm	60 m	0.6 m	360.000 pts/s	8 mm	After acquisition	None	1000 g

Table 2. Camera specifications.

Model	Sensor				Lens		
	Effective mpx	**Type**	**Stabilization**	**Shot on**	**Focal (35mm)**	**Autofocus**	**Aperture (f)**
Nikon D810	36.30	Full Frame CMOS	No (tripod)	JPEG (fine)	21	Phase detection	Continuous 2.8
DJI Mavic 2 Pro	20.00	1" CMOS	3-axis	RAW	28	Contrast detection	2.8-11

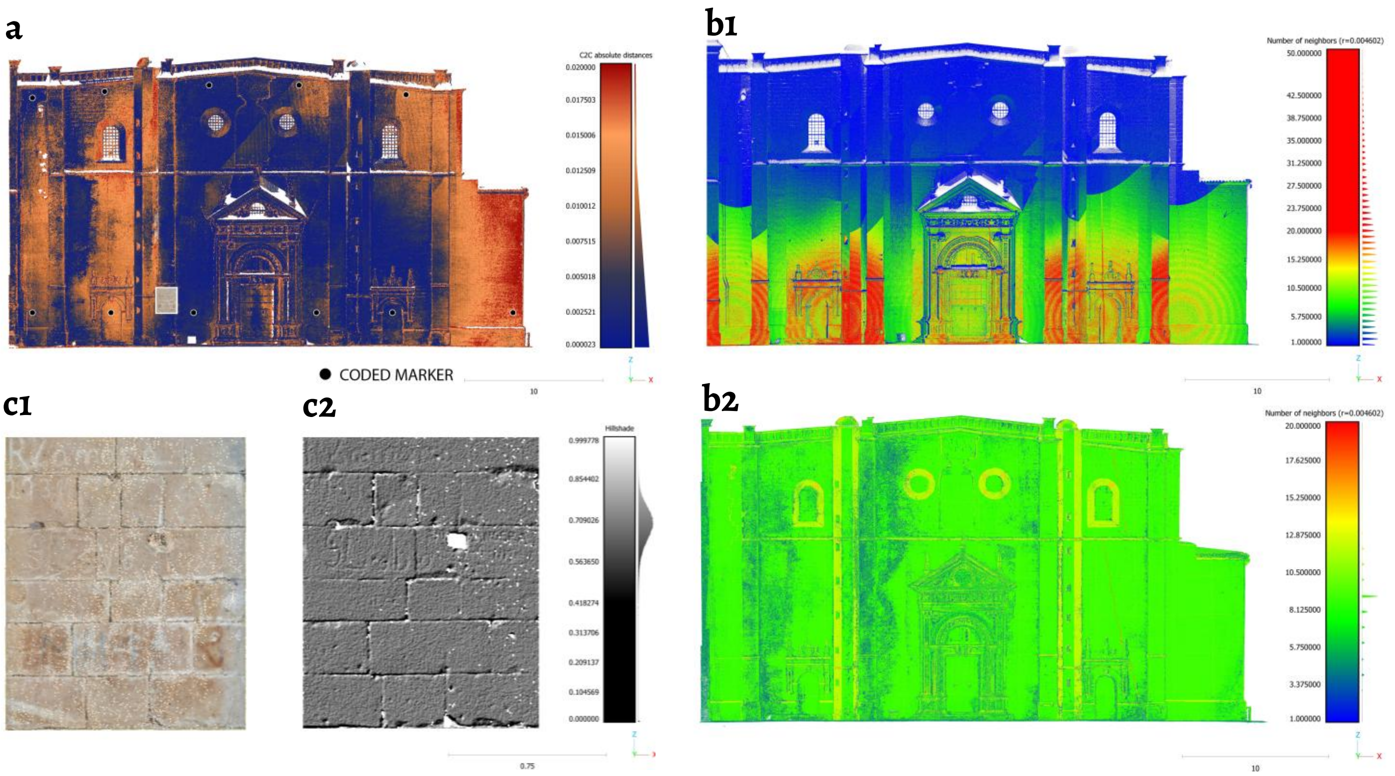

Figure 4. Hypothesis: *a)* Deviations between the cloud obtained by photogrammetry and the cloud obtained with the scanner; *b)* point density (number of neighbours) of the scanner point cloud (b1) and the photogrammetry point cloud (b2); *c)* relief surface detail: point colors view (c1) and Hillshade view (c2).

To check the geometric accuracy of the photogrammetry, we compared the drone cloud with the scanner cloud by aligning them in CloudCompare 2.13 with the ICP (Iterative Closest Point) procedure [14]. Next, we calculated the direct cloud-to-cloud distance using an approximation of the Hausdorff method [15]. This demonstrated that the distance variations between the two clouds are practically imperceptible, except for the right angle of the facade where more photographs would have been needed (Figure 4a).

Figure 5. Exploded orthophoto of the main facade and detail of the cartouche from 1533.

After validating the quality of the point clouds, we generated a series of images to analyze and illustrate our research. With the indoor and outdoor scanner cloud, at CloudCompare we obtained see-through visualizations generating a large JPG without altering the scale of the dots [16]. On the other hand, to calculate the best fit plane deviation in Figure 8, which we discuss later, we generated a Height Map (DEM) following two steps in CloudCompare: i) we created a plane on the reference wall section based on a representative selection of points on the surface (via Fit Plane); and ii), we calculated the distance between the plane and the point cloud (via Cloud/Primitive Dist.), the depth information was stored as a scalar value of the 3D cloud [17-19].

Also in CloudCompare and for specific cases, like checking elements that were not visible in the 2D photographs (Figure 4c-1), such as incisions, depressions, etc., we generate a Hillshade view (Figure 4c-2), through the Rasterize command selecting the most favorable sun position, of the cloud with a more homogeneous density, i.e., that of the photogrammetry (Figure 4b-2). Lastly, in Agisoft Metashape we generated orthoimages of the main planes of the facade, selecting manually the photographs for better orthophoto creation [20]. This produced a combined orthophoto with a resolution approaching the gigapixel size (Figure 5) [21].

Results and discussion: an approximation to the building process of the main facade of the collegiate church

The influence of the terrain in the initial phases of execution

As mentioned in the introduction, the study of the facade must take into account the ways in which the church was adapted to its urban vicinity, given that the highly uneven topography of the site impacted the building process.

An extensive system of retaining walls was erected to regularize the natural terrain, defining a horizontal plane of support that stretches beyond the church boundaries to generate a horizontal platform around the north, west and south facades (Figure 2). To the west, the archaeological data suggests the existence of an asymmetrical double flight of steps adapted to the topography. The remains were discovered during archaeological excavations carried out in the El Higueral sector. The archaeological report has not yet been published, but we refer to the information included in [22]. These steps define a profile of the terrain that is fairly close to what we see today (Figure 3). Consequently, the terrain on which the church was built presented a sharp south-west gradient similar to the current one, with a difference in height of more than four meters.

In the western sector we located several spaces beneath the level of this esplanade, two inside the church and one outside. Near the entrance, on the Epistle side, the crypt of the Chapel of the Kings, owned by the Alaya family, was built (Figure 2a), at least, since 1601, when the interior walls were painted [23]. Also, near the entrance, a large crypt was excavated in 1797, possibly accessed from the former crypt (Figure 2b). Outside the perimeter of the church, a vaulted structure was built under the platform, taking advantage of the difference in height, to serve as a cryptoportico with external access (Figure 2c).

Curiously, these spaces adopt a different layout (Figure 6). The crypt from the late eighteenth century maintains a safety distance from the nearby constructions – both the facade and the line of interior piers – in keeping with a procedure commonly followed in excavations to preserve the integrity of nearby foundations. However, both the Ayala crypt and the cryptoportico extend right up to the facade wall, without respecting this safety distance. The position of these two crypts adjacent to the wall is explained by the fact that these spaces were not excavated but built, taking advantage of the difference in height that existed at the south-west corner between the horizontal plane of the platform and the natural terrain.

This wall shared by the cryptoportico and the Ayala crypt is the continuation of the facade wall and reproduces the buttress and stairwell at a semi-underground level, albeit with a greater thickness. We therefore believe it is a basement wall that was necessary to reach the foundations, located below -4.00 m (Figure 6 and Figure 7). Given the continuity between the ribs of the vaults and this extension of the wall facade, and the embedded position of the side arches in that wall, the cryptoportico must have been built at the same time as the church facade. These data were deduced from the analysis of the cryptoportico walls performed with the high-resolution scanner (Figure 7).

We conclude that the terrain on which the works for the new church began presented a depression at the south-west corner that led to the construction of retaining walls and a basement wall that extended the facade down to the foundation level. The cryptoportico and the Ayala crypt were built between these walls. This represents a first phase of execution based on a general set-out survey of the church on two levels: on the Gospel side, the works were carried out at approximately the floor level of the church, while on the Epistle side they were conducted four meters below that floor level (Figure 7).

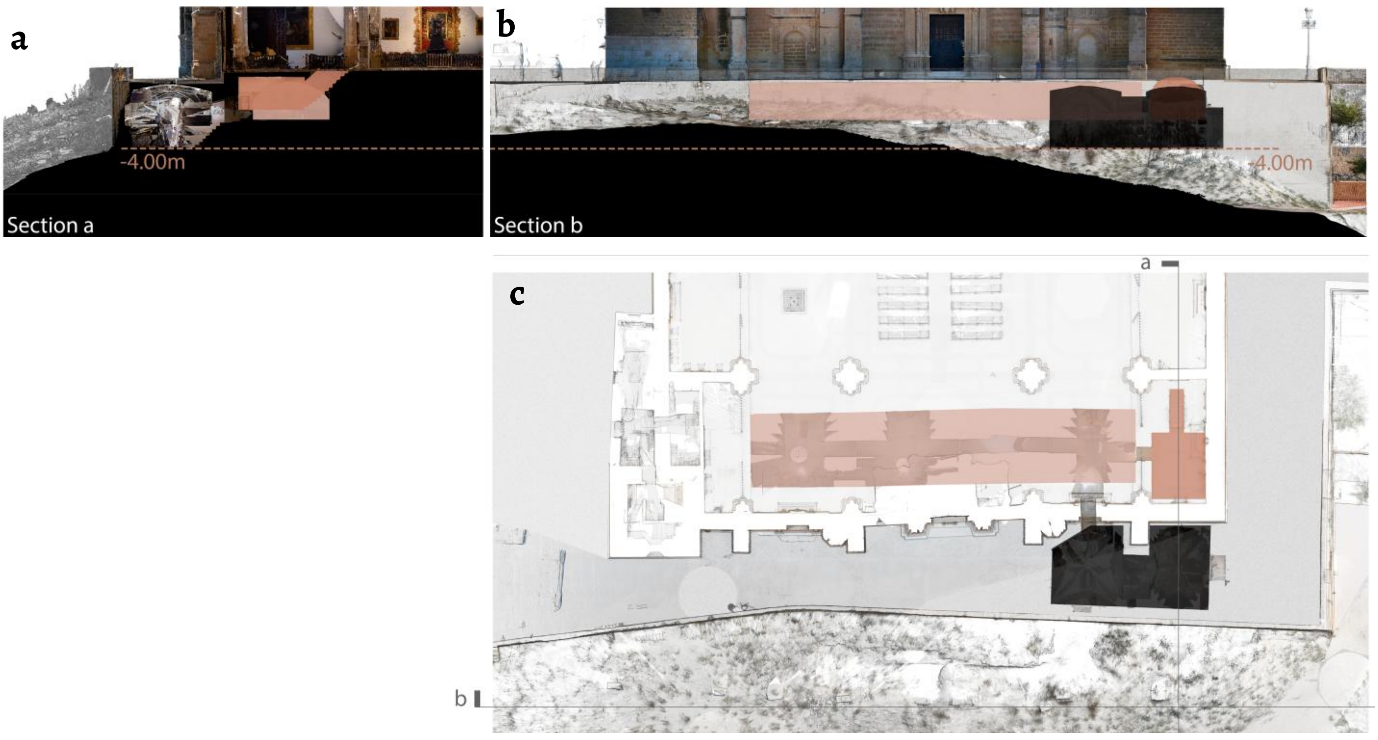

Figure 6. Sections through the west crypts: *a)* cross-section; *b)* longitudinal section; *c)* floor plan.

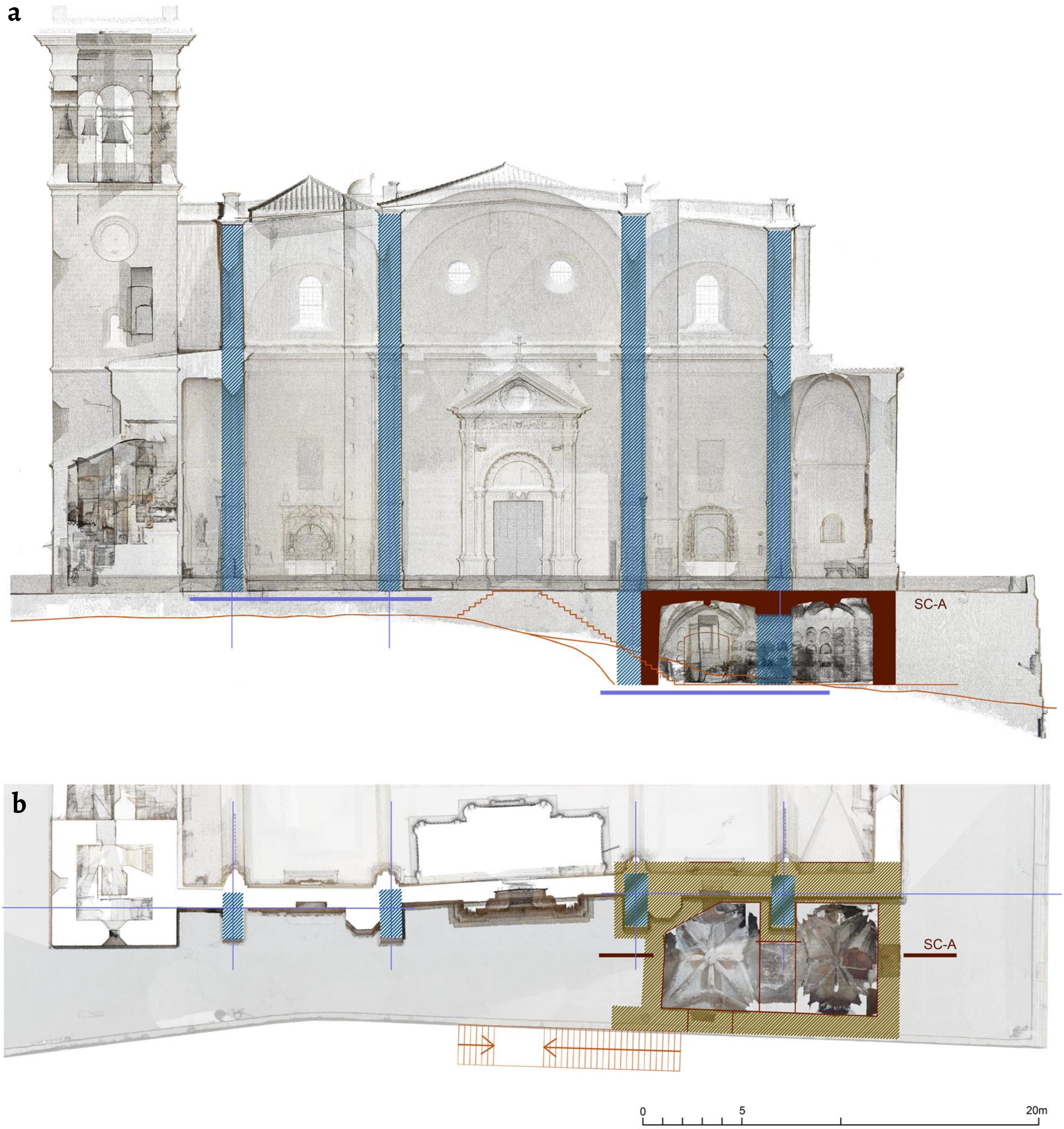

Figure 7. Facade indicating the internal structure of the nave and aisles and possible staircase: *a)* floor plan; *b)* elevated plan. The initial construction levels are indicated in purple.

Alterations introduced due to the different set-out survey levels

Before explaining the geometric distortions, we must point out two important aspects.

The first is the possible existence of two separate teams working simultaneously, one on the Gospel side and the other on the Epistle side. Inside the church, the study of the mason's marks reveals that these two groups worked more or less independently, one on each side of the nave [4]. This led to small discrepancies in the solution adopted for the pier bases, differences in the quality of the stonework, and the hasty resolution of certain elements on the Epistle side. This same duality is discernible on the facade: the buttresses on the Gospel side present a continuity with the brick courses but this is not the case with the ones on the Epistle side. Furthermore, the openings for the stairwells are inserted at different heights and on different faces of the octagon (Figure 5). The work at different levels that we suggested above supports the existence of these two teams working simultaneously.

Secondly, the Gospel side evidences greater regularity in the proportions and dimensions, which are more closely adapted to whole values in Castilian yards. This indicates that the set-out survey for that sector was more accurate than the one for the Epistle side. We therefore take the orientation and position of the facade section corresponding to the nave, aisles and Gospel chapels as the "correct" placement and closer to the master's set-out survey.

Assuming this hypothesis for operative purposes only, a comparison of the geometry of this sector of the facade with the rest of the elevation reveals that the symmetrical section, corresponding to the nave and Epistle chapels, presents a significant horizontal displacement (Figure 8). However, the correspondence that is clearly discernible between both facade sections cannot be coincidental.

The area marked as 1 (Figure 8b) is the reference plane. The wall of the gospel chapels has also a height of 0.00 m. Although the walls of the epistle and its chapels are separated, they have a constant distance of about 0.41 m and, therefore, are parallel to sector 1.

In between, the central section of the facade appears to deliberately reconcile the two orientations established in the aisles. The unusual geometry of this section of the facade and its nature as a type of "adjustment piece" are visible on the interior face, where the overlap of the side piers is avoided by reducing their thickness with respect to the adjacent wall sections.

We hypothesize that the complex execution resulting from the conditions described above – primarily, the existence of two teams working at two different levels – led to a significant set-out survey error between the two simultaneous work areas. This error did not affect the orientation of the two sections, which could easily be checked, but it did impact their total length, since working on sloping terrain and making transversal checks and adjustments demanded a degree of expertise.

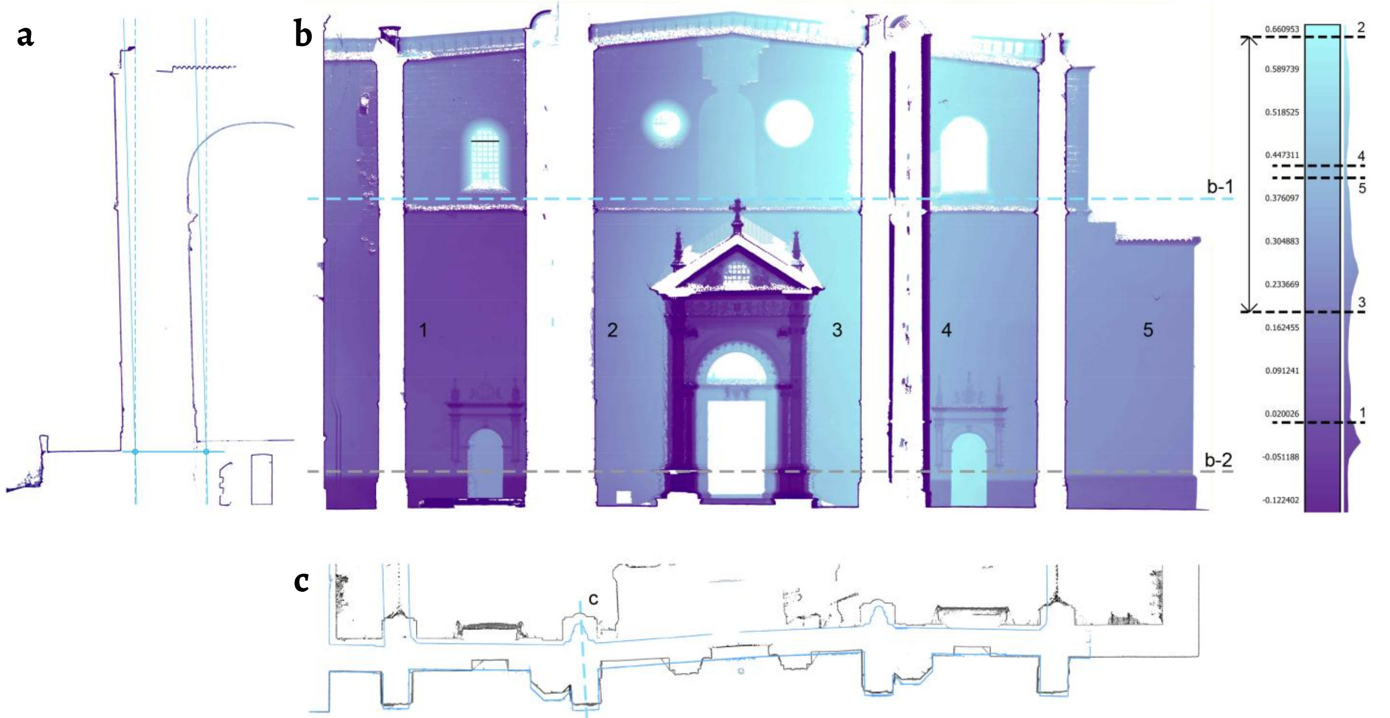

Figure 8. Facade views: *a)* elevation with deviations of the facade wall surfaces with respect to a selected plane; *b)* horizontal cross-sections of the facade at different heights; *c)* cross-section through a buttress.

Building process and material diversity

The study of the facade materiality enabled us to assess its extraordinary heterogeneity in relation to two important issues: i) whether it obeys aspects of the original design or subsequent modifications of the Renaissance proposal; and ii) whether it obeys the existence of reused building elements on different surfaces of the facade.

The buttresses

The first elements we analyzed were the buttresses, whose singular characteristics presupposed their consideration as independent building units.

In the orthophotos, the lower section of the facade reveals a lack of material continuity between the buttresses, the stairwells of the spiral staircases and the adjacent wall surfaces (Figure 9a). The buttresses and staircases were executed with a more compact and better quality of stone, possibly brought from the nearby town of Estepa [24]. They were cut with precision and bonded with minimal joints, especially between stones, whereas the general wall surfaces were built out of a local porous stone, cut in an irregular fashion and bonded with generous joints. The position of the horizontal rows also displays significant variations between the stairwells, buttresses and general surfaces (Figure 9b).

The section above the main cornice displays a material homogeneity and greater continuity between surfaces (Figure 9a). The better quality of stone has disappeared and the rest of this entire section of the facade is executed with the stone used for the facade walls. In addition to the use of the same type of ashlar, the continuity detected in the rows of the surfaces and the buttresses suggests that they belong to the same construction unit. However, although the same material was used for the stairwells, there is a discontinuity between the rows, which are situated at a different level (Figure 9b). We therefore deduce that the buttresses and general wall surfaces were executed simultaneously, while the stairwells were built at a slightly later time, probably because these stone blocks were more complex than the rest of the facade.

Figure 9. Facade panel analysis: *a)* materials; *b)* continuity of bed joints.

The correspondence between the facade walls of the vaults and this continuous elevation formed by the buttresses and surfaces of the upper section of the facade suggests that these elements were all executed together. The comparison of the collapse of the buttresses and of the facade wall support this hypothesis (Figure 8a). The angle of inclination is exactly the same, confirming that the facade did not undergo any thrusts before the buttresses were executed. This also disproves the hypothesis formulated in other studies about the possible execution of the buttresses to resolve thrust issues caused by the vaults [7].

In addition to this continuity in the upper section of the facade, the aforementioned presence of the facade buttress on the basement wall below the floor level of the church, corresponding to the first phase of the building works, enables us to conclude that the buttresses formed part of the original facade design, assuming that a vaulted system to cover the church was envisaged from the outset. The difference in the size and material of the ashlars of the buttresses and walls in the lower section justifies the lack of continuity between these elements, while the difference in quality between the stone used in the lower and upper sections of the buttresses obeys a reduction in building costs that is also discernible inside the church, where above the same level the better-quality stone was abandoned, the ornamentation was reduced and the ribs in the vaults were simplified.

The continuity of surfaces

The hypothesis about the simultaneous execution of the buttresses and wall surfaces does not rule out the possibility that a specific section of the walls was built earlier or later than the rest of the facade. Our analysis of the continuity between the elevations of the nave and aisles sheds light on this matter.

The central section displays an inferior type of bond that is not repeated anywhere else on the facade. Its layout is related to the execution of the main portal for two reasons: i) the rows of brick in the bond serve to align the stone bed joints in the wall with the configuration of the stones in the portal; and ii) this inferior bond is delimited by the shape of the pediment (Figure 10).

Figure 10. Detail of the main portal: continuity of stone bed joints thanks to the rows of brick.

Above the portal and these adjacent sections is a complete section executed with the general bond used for the facade that we mentioned earlier (Figure 9b). This same bond was used on the entire vertical deployment of the aisle and chapel elevations. All three portals that were resolved with a bioclastic limestone [9], a better quality of material more appropriate for stonework (Figure 9a). In addition to sharing the same material and type of bond, the last rows beneath the main cornice of the nave, aisles and side chapels display a clear horizontal correspondence with the central section, with coordinated bed joints, offering unequivocal evidence of the existence of a common building process (Figure 9b). Consequently, the continuity between the surfaces above the main cornice, as mentioned above, is also observed in the rows below the cornice, up to the height of the central portal.

We can therefore assert that the facade walls were executed during the same building process, except for the section around the main portal where we can only surmise its sequence in the overall process: namely, that it corresponds to an execution unit completed before the rest of the facade and was therefore the first section built above the floor level of the church.

Proposed timeline of building phases

Lastly, we divided the time frames for the execution process into three phases.

The first one is easy to establish because of the cartouche that pinpoints the portal and adjacent facade wall to the year 1533 (Figure 5).

As for the second phase, there are compelling reasons to consider that the interior and exterior were designed simultaneously. For one thing, there is a clear geometric and structural concordance between the facade and the church nave and aisles. Furthermore, there are nearly 30 types of mason's marks present on both the facade and interior piers [4]. This design likely corresponds to the Renaissance church of the second third of the sixteenth century, probably begun by Diego de Riaño and completed by Martín de Gainza. If we accept this hypothesis, the second phase must have been a continuity of the first phase, occurring after 1533 or 1534. Why this material discontinuity between two phases that possibly belong to the same building process? We cannot offer a reasoned explanation for this, but we must consider the possibility that the stones in the portal, a separate workshop element, had been delivered to the site at an early date in the process and the portal was erected in its definitive position before the material for the rest of the facade had arrived. This would explain the adaption of the facade wall to the portal geometry and the use of a bond that was not repeated anywhere else in the building.

The third phase, which includes all the elements above the main cornice, was likely the continuation of the second phase and was completed in about 1537, when the bylaws for the new collegiate institution were published and read by the church council from the choir [1]. The church must have had a roof by then, as this would have been necessary to ensure appropriate conditions for the ceremony to take place. However, we cannot infer that the vaults had been executed because if a timber roof existed, it was common practice to build this before the system of vaults, using the timber framework for support [25-26].

Conclusions

The analysis of the geometric characteristics of the facade confirms the existence of sharp deviations between the orientations of the facade wall surfaces. Furthermore, the study of those surfaces clearly reveals the lack of correspondence between the walls, buttresses and stairwells up to the level of the main cornice, all executed with different materials and bonds. As is made clear throughout the article, this lack of continuity is not the result of chronologically distant construction phases. The study of the initial stages of execution of the church provides a reasoned explanation for the significant geometric deviations between surfaces, attributable to problems during on-site layout and not to different construction phases, while the detailed analysis of the materials seems to confirm a continuous time frame for the overall execution, although probably within a complex and uneven construction process. In summary, we can confirm as the main conclusion that the main facade of the church corresponds to a continuous construction process, associated to a single construction unit that would include the pillars, walls and vaults of the central and lateral nave. Therefore, its overall execution is related to the design of the Renaissance collegiate church of the second third of the sixteenth century.

The material characterization of the facade, including the precise dating of its components, serves as a starting point for a proper heritage evaluation for future restorations, ensuring that there are no errors of interpretation that involve the transformation or demolition of original architectural elements. In this case, the entire facade should be considered as the result of the Renaissance project, of great architectural value and worthy of being preserved as far as possible.

Lastly, the increased density of the data collected offers new analysis possibilities, two with particular application to the study of heritage buildings: i) improved software for analyzing surfaces with point clouds opens up interesting fields for studying deformations, orientations or surfaces; ii) the use of the different point cloud attributes permits new forms of graphical representation and analysis.

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