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Geometry in 18th Century Bell Towers in Bajo Segura, Spain

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Abstract: Bell towers are essential elements of religious architecture, which have been part of villagers' lives for centuries and have marked their identity and orientation from a far distance. This research provides widens our knowledge of geometrical aspects of bell towers through a search for common building patterns. Throughout the history of construction and architecture, there have been specific studies about particular bell towers, but few have taken a more general approach, studying 18th-century architectural treatises and building warnings for ecclesiastical buildings after the Council of Trent. In the Spanish ecclesiastical territorial organisation, the Diocese of Orihuela and its region (Bajo Segura) had great importance, with outstanding social development and territorial expansion due to the colonising action of the clergy and nobility in the 18th century. In 1829, an earthquake had destructive effects on the area's architectural heritage. This paper studies the bell towers that endured the earthquake by recording data in situ, generating a catalogue, and analysing and comparing the data obtained. The results outline a construction model that meets the established guidelines of the architectural treatises as far as geometrical proportions and building patterns are concerned.

Keywords: tower; bell tower; architectural heritage; geometry; earthquake; Bajo Segura; 18th century

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1. Introduction

1.1. Bell Towers

This research makes a start at analysing bell towers, which are considered essential elements in the architectural heritage of Christianity, regardless of their relative position concerning the Church plan they are attached to. A bell tower is an element with its own identity and it represents an important visual reference in the region. In some cases, bell towers have been disturbed by the development of urban construction, which has led to a loss of their identity as social and religious icons.

The ecclesiastical administrative organisation in Spain divides the area into several Dioceses. The town Orihuela, capital of the Alicante region of Bajo Segura, has been the Episcopal See for almost 400 years (1564–1959), and experienced outstanding urban and demographic development during the 18th century. This fact together with colonisation strategies fostered church building projects whereby bell towers took on a leading role in the urban fabric and scenery. They became an orientation point on the horizon, a reference for time with their clocks, and a signal of important or emergency moments with their bells.

In 1829, the Bajo Segura constructions suffered a serious earthquake, which marked a turning point for the existing architectural heritage. This research studies those bell towers that have survived to the present day and were not destroyed by the earthquake.

1.2. Background

The knowledge of the bell tower as an architectural typology [1–6] implies the study of different constructions analysed from two points of view: as autonomous elements with certain constructive and compositional characteristics, and as a response to processes of social and urban development that demand certain architectural solutions. These approaches make a better understanding of the bell tower possible as a recognisable element in the architectural legacy of the Christian social tradition. Of relevance in Spain (Valencian region), we can mention papers such as "Reflexiones en torno a los viajes de A.J. Cavanilles por tierras de Valencia (1791–1793)" or Cavanilles' own papers [7,8] with descriptions of the area seen from the bell towers in the region.

In addition, some research is linked to the area as well as spatial, demographic, and economic structures [9–14], in which colonising processes in the region throughout the 18th century are studied.

From an architectural and constructive point of view when considering bell towers, we highlight Francisco Juan Vidal's book (2000), "Los campanarios de José Mínguez. Valencia 1700–1750" [6], where he studies the work of the architect José Mínguez, to whom some of the best-known bell towers of the Valencian baroque are attributed in the first half of the 18th century; the book makes conclusions on this particular model of bell tower. In other regions, studies such as that by José Javier Azanza López (1998) of Navarra University, "Tipología de las torres campanario barrocas en Navarra" [1], can be found. He studied the towers of the last third of the 17th century and the 18th century of the Navarrese baroque, where he established three typological varieties depending on the geographical area where they are located. No less interesting is the lecture paper presented by Miguel Ángel Chamorro Trenado at the Sixth National Congress on the History of Construction (2009), "Los campanarios góticos de las comarcas gerundenses: tipologías y sistemas constructivos" [2], in which he described the typology and construction system of bell towers located near the city of Girona. Other investigations study the seismic behaviour of bell towers [9,10] or their dynamic action introduced by the ringing of bells [11]. These publications are references for this research, which takes place in a defined spatial and temporal scope: the Bajo Segura region, within the province of Alicante, in the 18th century.

To add to the existing literature, this research verifies a typological model of a bell tower that has certain compositional and constructive characteristics, as well as a certain level of compliance with the warnings that the Church makes following the Council of Trent (1545–1563) in three documents on religious architecture, completed a century before the cases studied were constructed. Those include Caroli Borromei's work "Instructionum fabricae et supellectilis ecclesiasticae" (1577), translated into Spanish in 1985 [12], "Synodus dioe-cesana Valentiae celebrata" (1631) by Fernando Pingarrón [13], which regulates sacred architecture in the construction of Christian churches, and mainly, the Architecture Treatise "Arte y uso de Arquitectura" by Fray Laurencio de San Nicolás (1639) [14], where recommendations on the proportions that must be met are described. All of these have served the search for a geometric pattern in this research.

1.3. Objectives

The main objective of this research was the compositional and geometric analysis of the selected bell towers, by comparing them and verifying the obtained data with the recommendations for design in ecclesiastical works established in the Treatise of Architecture after the Council of Trent.

From this main objective, a practical path was sought to provide the necessary architectural data to understand the concept of bell tower construction, determining the common and differential aspects that they present with their architectural composition, by obtaining and analysing the parameters that relate them and establishing a bell tower pattern in the Bajo Segura region supported by technical data. This was achieved via a metric and constructive study of 15 selected cases, checking whether a pre-established and recommended model was constructively followed.

2. Methodology

To conduct the study within the established limits, different organised research methods and techniques were used. They evolved from a general study to a more particular one, marking the trajectory of the research. During data collection, a database was constructed with diverse information brought together to assess the variables under study.

2.1. Historical and Documentary Analysis

This work represents an approach to demarcating the historical context of the Bajo Segura area under study. There is little information about bell towers as most focuses on the Churches they belong to. Within the chosen temporal and spatial scope, few archives preserve manufacturing books related to the construction of towers.

For compositional and geometric characterisation, architectural treatises written since the 15th century have been consulted. They set out the geometry and way the bell towers should be built in great detail. The most widely consulted treaty for this research is "Arte y Uso de Arquitectura"—the first part, by Fray Lorenzo de San Nicolás (1639) [14]—since it is considered one of the most relevant texts for the construction of numerous building elements such as stairs, vaults, walls, foundations, etc. This treaty devotes a particular chapter to how to design and build a tower. In the treatise written by Atanasio G. Brizguz y Bru (1738), architectural orders, advice on the distribution of towers and houses, and knowledge of materials appear [15]. It refers to the bell tower building, and further, to the quality of the materials used for construction.

Curiosity about whether or not sacred architecture was regulated throughout history led us to a search for specific documentation. We found that after the Council of Trent (1563), Carlos Borromeo began regulating such architecture, publishing the highly commented on "Instructionum fabricae et supellectilis eclesiasticae" in Milan in 1577. When building the Autonomous National University of Mexico, the architects consulted a publication from the aforementioned document [12]. Years later, in Valencia, a new document following Trento regulations was published to regulate the religious architectural space. It had a similar title to Carlos Borromeo's: "Advertencias para los edificios y fábricas de los templos: y para diversas cosas de las que en ellos sirven al culto divino y a otros ministerios". This work was based on the synod of the Isidoro Aliaga Archbishop in 1631. It has been possible to consult a transcription by Fernando Pingarrón, professor of Art History at the University of Valencia, who studied the original document [13].

2.2. Selection of Case Studies

Once the temporal scope (last third of the 17th century and 18th century) and spatial scope (Bajo Segura region in the province of Alicante-Spain) were established, municipalities (among the 27 that form the region) that had one or more tower built during the given timeframe were selected.

Nine municipalities met the requirements to be included in the study. The remaining villages had towers built previously or rebuilt after the earthquake that devastated part of the region in 1829, with its epicentre in the triangle formed by Torrevieja, Rojales, and Benejúzar, as shown in Figure 1. For this reason, they fell outside of the established timeframe, as they were rebuilt during the second half of the 19th or in the 20th century. Taking our approach, one-third of the villages were within research scope, namely: Albatera, Benferri, Bigastro, Catral, Cox, Daya Nueva, Dolores, and Orihuela y San Fulgencio. These population centres are located in the northernmost area of the region and on the left bank of the Segura River, except for Bigastro, which is on the right bank. Once the municipalities that met the parameters to undergo the study were defined, the search for data on the bell towers began. Data such as the name of the tower, construction period, architect, and year in which the bells were finally placed were recorded.

Analysis of these data laid out common characteristics that led to the establishment of a generalised bell tower model. Among the selected municipalities, Orihuela stands out with a high number of religious buildings. Table 1 displays a list of the studied bell towers, including the period in which the bell tower was finished [16]. Taking into account the framework of the proposed research, 15 bell towers located in nine municipalities of the

Bajo Segura region were included in the study. All were built during the late 17th century or 18th century.

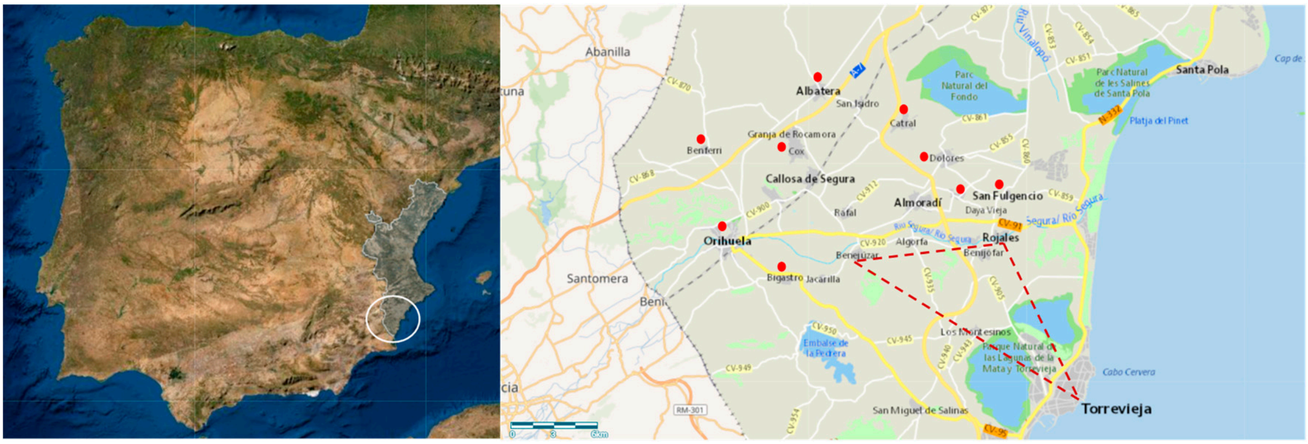


Figure 1. Locations of the nine selected municipalities in Comarca Bajo Segura, Alicante. The dotted lines represent the triangle where the epicentre of the 1829 earthquake in the region was located.

Table 1. Definitive list of the 15 case studies for the research, indicating the period of completion of the bell tower [16].

	Chronology of Construction of Temples and Bell Towers	Previous	1700–1710	1711–1720	1721–1730	1731–1740	1741–1750	1751–1760	1761–1770	1771–1780	1781–1790
1	Cox Iglesia Ntra. Sra. del Carmen										
2	Orihuela Iglesia Ntra. Sra. del Carmen										
3	Benferri Iglesia de San Jerónimo										
4	Bigastro Iglesia Ntra. Sra. de Belén										
5	Albatera Iglesia de Santiago Apóstol										
6	Orihuela Iglesia del Colegio Santo Domingo										
7	Daya Nueva Iglesia San Miguel Arcángel										
8	Orihuela (Clarisas) Iglesia San Juan de la Penitencia										
9	Catral Iglesia de los Santos Juanes										
10	San Fulgencio Iglesia de San Fulgencio										

Table 1. *Cont.*

Chronology of Construction of Temples and Bell Towers		Previous	1700–1710	1711–1720	1721–1730	1731–1740	1741–1750	1751–1760	1761–1770	1771–1780	1781–1790
11	Orihuela Santuario Ntra. Sra. de Monserrate									■	
12	Dolores Iglesia Ntra. Sra. de los Dolores									■	
13	Cox Iglesia de San Juan Bautista									■	
14	Desamparados Iglesia Ntra. Sra. de los Desampara-dos										■
15	La Aparecida Iglesia Ntra. Sra. de Belén										■

The architects and master builders involved in the 15 buildings studied, in most cases, came from families settled in the region, such as Miguel de Francia García, Damián Francia Guillén, Fray Francisco Mendoza, and Pedro Gilabert, and completed work linked to the religious architecture of the region. All of them applied constructive knowledge and made geometric decisions according to a certain architectural composition similar to that of the constructions in the Valencia region designed by Juan Mínguez, which have greater dimensions but incorporate the same architectural patterns [5,6].

2.3. Direct Data Collection

Fieldwork allowed us to gather the necessary information to conclude on correlations between the different metric, photographic, and building data obtained on visits to each bell tower. From this direct data collection, the following information was obtained:

- General and detailed metric data. We made bounded freehand sketches of ground plans and sections as well as the elevation and related details. Figure 2 displays such a sketch. Those data served to create a database of the elements under study, to enable their analysis in isolation. It is essential to obtain individual data to be able to compare, quantify, and assess all factors under consideration.
- Photo documentation. We made an extensive photographic report of both the interior and exterior areas of each bell tower we visited. This was necessary to observe and later recall details (Figure 3).
- Building data. Via organoleptic inspections of the bell towers that had not been reformed, and therefore, left construction details visible, we made note of the materials, geometry, and constructive solutions to their execution. Concurrently, a general database of qualitative and quantitative parameters was created for each case study, including diverse information on wall thicknesses, heights, interior and exterior widths, staircase typologies, framing, the roof, gaps, and the locations of the tower and crowning.

To ascertain this information, complementary traditional and technological methods were used. To determine whether the original configurations of restored towers could be obtained, thermographies were conducted with a FLIR P-25 model camera.

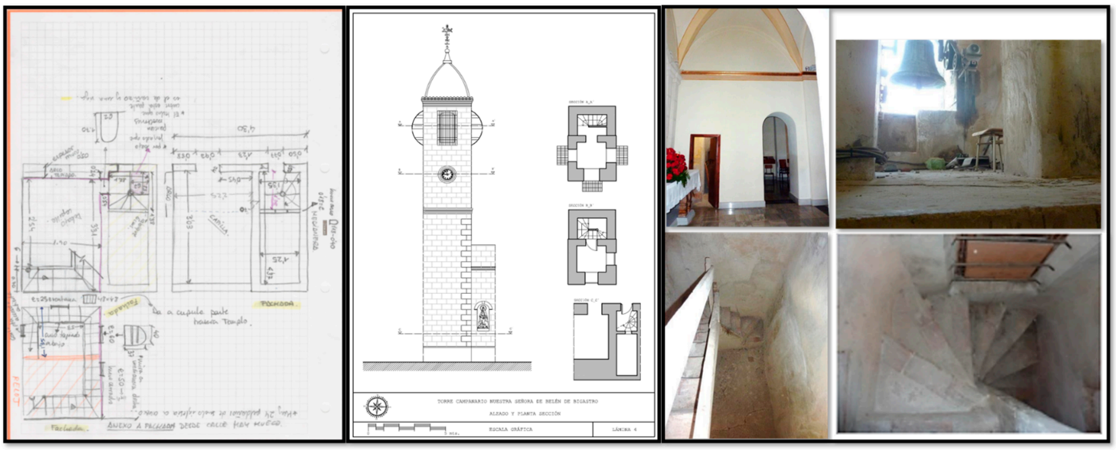


Figure 2. Example of direct measurements. Sketches, scaling, and photographs of the interior of the bell tower of N.S. de Belén of Bigastro.

Figure 3. Photos taken inside the bell tower N.S. de los Dolores.

2.4. Catalogue

Using the information obtained in the previous phases, detailed and ordered descriptions of the 15 cases under study were produced. The situation and setting they occupy, the historical background, the compositional and constructive architectural characterisation of both the interior and the exterior areas of the bell tower, and the geometric characterisation obtained during direct data collection were considered. At the same time, scaling was carried out using the sketches, annotations, and photographs, thus creating a graphic representation of the elevations and various ground plans of the case studies (Figures 4 and 5). We organised the work in schematic files where relevant data for the research were noted at historical, architectural, and constructive levels (Figure 6).

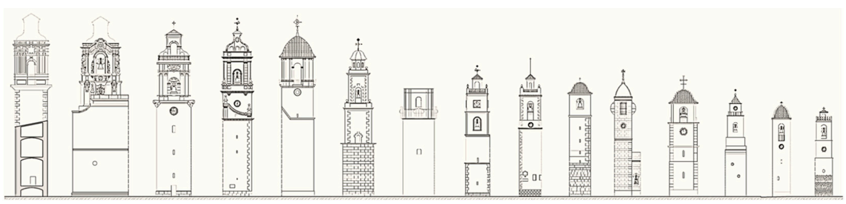
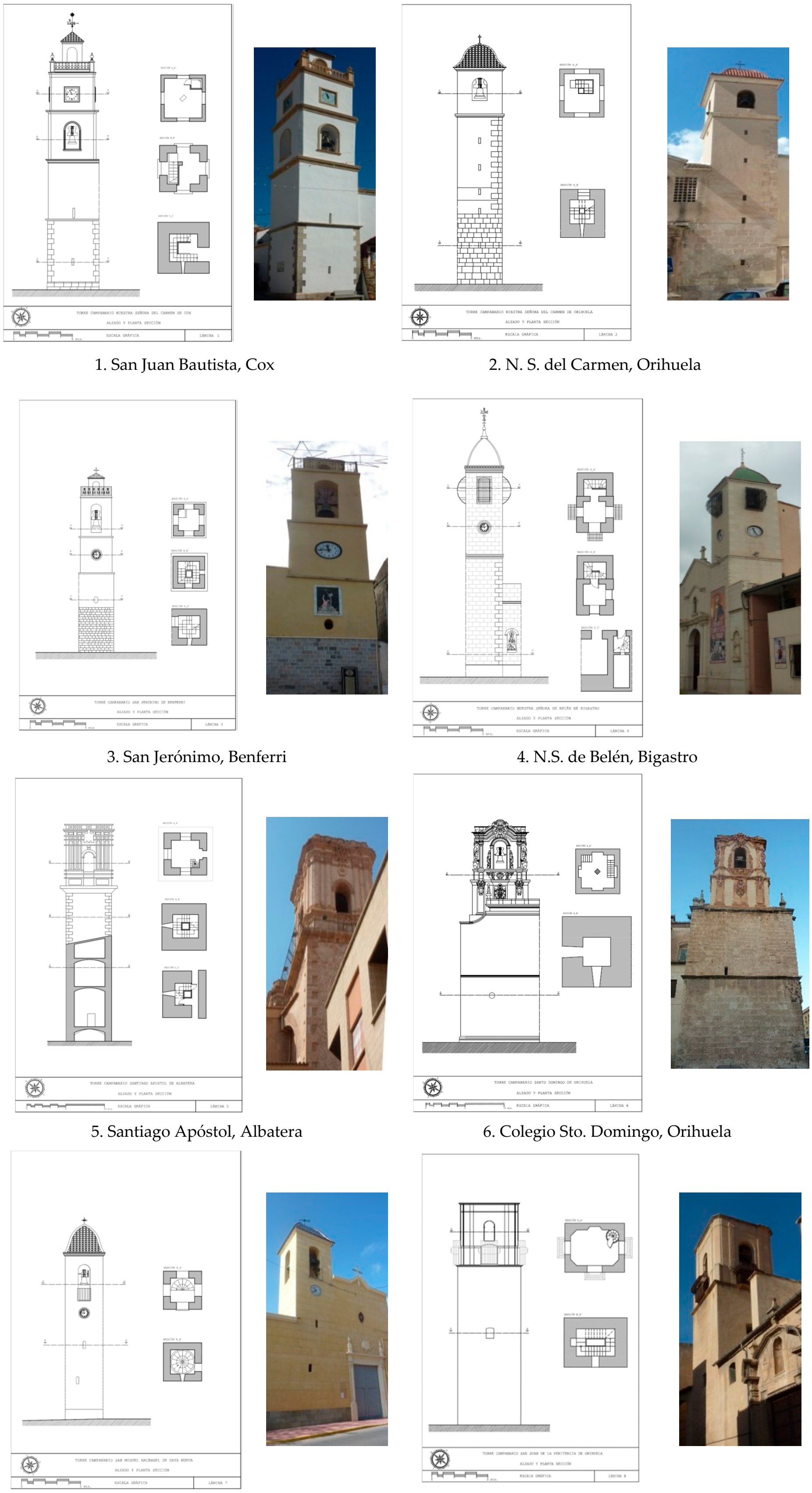
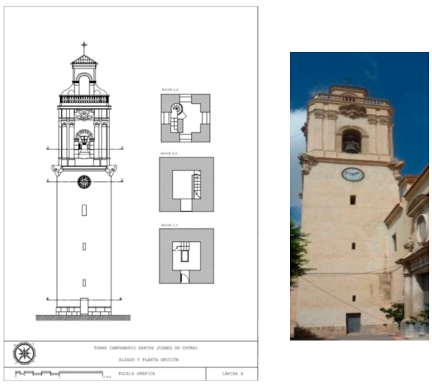


Figure 4. Comparative image of the 15 bell towers.

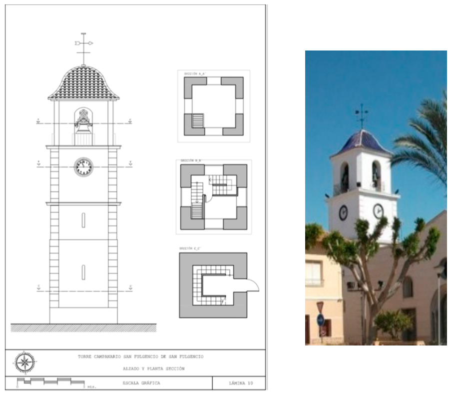


1. San Juan Bautista, Cox
2. N. S. del Carmen, Orihuela
3. San Jerónimo, Benferri
4. N.S. de Belén, Bigastro
5. Santiago Apóstol, Albatera
6. Colegio Sto. Domingo, Orihuela
7. San Miguel Arcángel, Daya Nueva
8. San Juan de la Penitencia, Orihuela

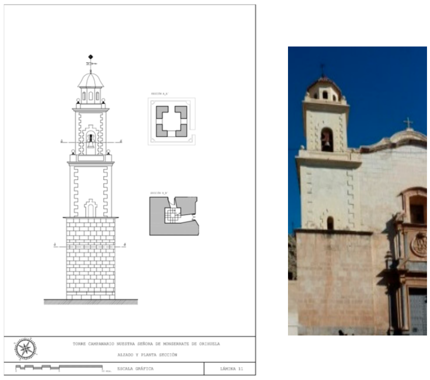
Figure 5. *Cont.*



9. Santos Juanes, Catral



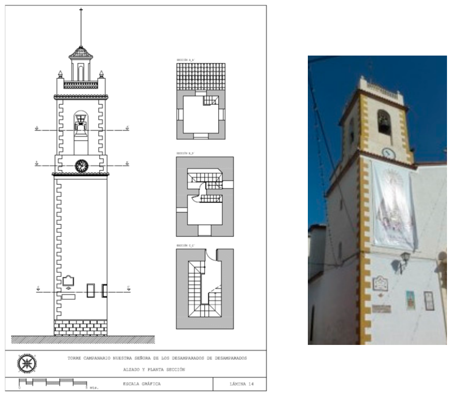
10. San Fulgencio, San Fulgencio



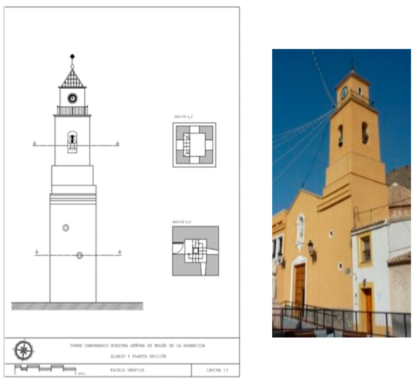
11. N. S. de Monserrate, Orihuela

12. N.S. de los Dolores, Dolores

13. San Juan Bautista, Cox

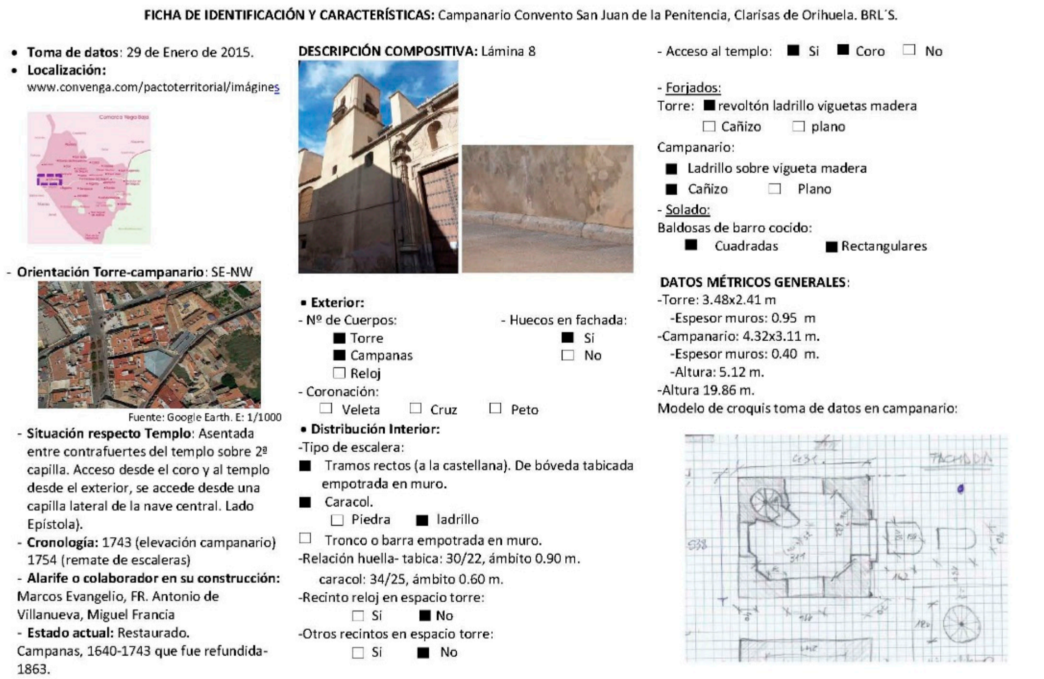


14. N. S. de los Desamparados, Desamparados



15. N. S de Belén, La Aparecida

Figure 5. Ground plans and elevations of the bell towers under study.



FICHA DE IDENTIFICACIÓN Y CARACTERÍSTICAS: Campanario Convento San Juan de la Penitencia, Clarisas de Orihuela. BRL´S.

- Toma de datos: 29 de Enero de 2015.
- Localización: www.convenga.com/pactoterritorial/imágines

- Orientación Torre-campanario: SE-NW

Fuente: Google Earth. E: 1/1000

- Situación respecto Templo: Asentada entre contrafuertes del templo sobre 2ª capilla. Acceso desde el coro y al templo desde el exterior, se accede desde una capilla lateral de la nave central. Lado Epístola).
- Cronología: 1743 (elevación campanario) 1754 (remate de escaleras)
- Alarife o colaborador en su construcción: Marcos Evangelio, FR. Antonio de Villanueva, Miguel Francia
- Estado actual: Restaurado. Campanas, 1640-1743 que fue refundida-1863.

DESCRIPCIÓN COMPOSITIVA: Lámina 8

• Exterior:
- Nº de Cuerpos: ■ Torre ■ Campanas ☐ Reloj
- Huecos en fachada: ■ Si ☐ No
- Coronación: ☐ Veleta ☐ Cruz ☐ Peto

• Distribución Interior:
-Tipo de escalera:
■ Tramos rectos (a la castellana). De bóveda tabicada empotrada en muro.
■ Caracol. ☐ Piedra ■ ladrillo
☐ Tronco o barra empotrada en muro.
-Relación huella- tabica: 30/22, ámbito 0.90 m. caracol: 34/25, ámbito 0.60 m.
-Recinto reloj en espacio torre: ☐ Si ■ No
-Otros recintos en espacio torre: ☐ Si ■ No

- Acceso al templo: ■ Si ■ Coro ☐ No

- Forjados:
Torre: ■ revoltón ladrillo viguetas madera ☐ Cañizo ☐ plano
Campanario: ■ Ladrillo sobre vigueta madera ■ Cañizo ☐ Plano
- Solado:
Baldosas de barro cocido: ■ Cuadradas ■ Rectangulares

DATOS MÉTRICOS GENERALES:
-Torre: 3.48x2.41 m
-Espesor muros: 0.95 m
-Campanario: 4.32x3.11 m.
-Espesor muros: 0.40 m.
-Altura: 5.12 m.
-Altura 19.86 m.
Modelo de croquis toma de datos en campanario:

Figure 6. Data collection.

2.5. Geometric and Dimensional Characterisation

Once the obtained data were arranged, they were analysed and compared to determine their meaning and identify a typical model of a bell tower. Data arrangement made it possible to conclude about the 15 bell towers investigated based on unique constructive elements related to these ecclesiastical buildings that followed certain parameters established before their construction.

Our graphical survey of their planes with dimensional values, for each of the visited bell towers, made it possible to verify their adaptation to one type of section or another, as well as whether their dimensions were representative of the sample on the whole.

To compare the obtained dimensional values, establish relationships between them, and verify whether they were built under the proportions recommended in the Treatise of Architecture and Construction for the 17th and 18th centuries, a database was created and the variables under study were calculated.

Descriptive and correctional analysis was performed using a statistical package (IBM SPSS v.22), calculating the statistics necessary to describe the variables and obtain Pearson's correlation coefficient. As there were 15 selected cases, the sample size and number of variables assigned to bell towers' characteristics were considered. Accordingly, a non-parametric method was used for the statistical treatment of the data [17]. Descriptive statistics for data analysis were obtained. Pearson's correlation was used as a statistical test to measure the magnitude of the relationship (supposedly linear) between the variables assigned to the geometric characteristics of the 15 bell towers, and the Kruskal-Wallis test was used to compare them [18]. The use of these non-parametric tests allowed us to analyse the relationship between the assigned variables.

From the point of view of architectural proportion, four variables were assigned (Table 2 and Figure 7) to check whether the selected cases met the proportions established in the Treatise of Architecture of Fray Lorenzo de San Nicolás and Briguz y Bru [14,15].

Table 2. Assigned variables to the elements measured in the bell tower.

Data Collection	Definition	Geometrical Characteristics Treated
H	Height at the top cornice of the bell tower	H = 4A
A	External width of the tower parallel to the façade	A = H/4
B	External width of the tower perpendicular to the façade	A = B
e	Thickness of the tower wall	e = 1/4 A

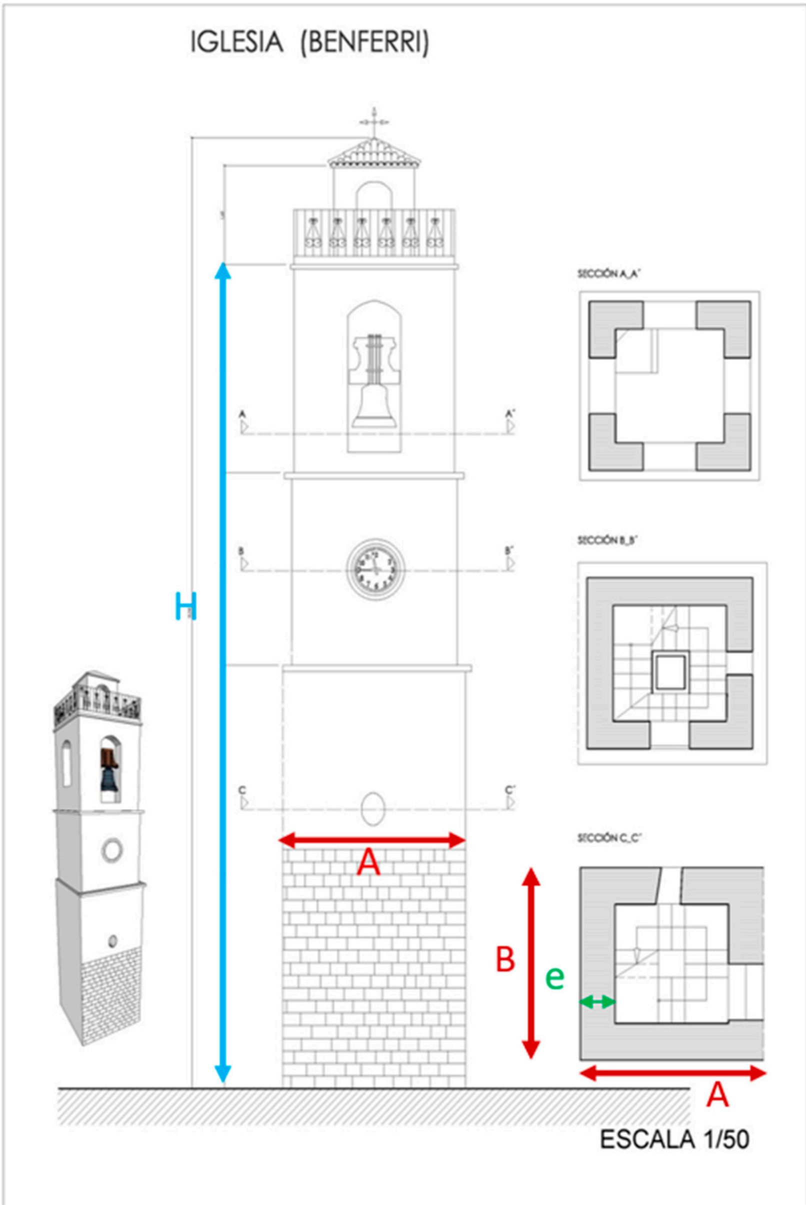


Figure 7. Diagram of variables applied in the study.

3. Analysis and Results

The analysis carried out focused on three aspects. Firstly, the descriptive values of the sample were studied, as well as the proportions that marked the architecture and construction treatise. Next, and given the characteristics presented by the data, non-parametric techniques were used for correlation analysis. Finally, a hypothesis contrast was carried out to analyse whether the proportions that marked the Treatise of Architecture and Construction aligned with those documented in the study cases. Table 3 shows the descriptive statistics obtained for the variables studied and for the proportions reflected in the Treatise of Architecture and Construction.

Table 3. Descriptive statistics of the analysed variables and proportions.

	Name	N (No. of Samples)	Minimum	Maximum	Mean	Standard Deviation
Variables	H	15	13.48	27.66	19.98	4.84
	A	15	3.10	9.60	4.94	1.65
	B	15	3.15	9.60	5.10	1.71
	e	15	0.60	2.50	1.19	0.48
Ratio between variables	A = H/4	15	3.37	6.92	4.99	1.21
	A − B	15	−1.21	1.07	−0.02	0.48
	e = A/4	15	0.78	2.40	1.23	0.41

As far as variables are concerned (Table 3), we can see that, on average, the height of the towers (H) reaches 20 m, although there are cases of below 15 m and others that exceed 25 m. Concerning the width of the tower parallel to the façade (A), the average values show that the towers have a dimension close to 5 m, although there are cases in which this dimension is almost double. Regarding the dimension of the tower perpendicular to the façade (B), on average it is slightly over 5 m, which shows that the equality reflected in the treatise is seemingly fulfilled. As for the dimension of the thickness of the tower walls (e), on average it is close to 1.20 m, although there are cases in which this thickness is double or half that. If we compare the values obtained for the first set of variables (A = H/4), on average, the value obtained differs by just 5 m, meaning it is very similar to that obtained for (A), which highlights the possible existence of a relationship, and therefore, we propose that the construction of the towers seems to follow the criteria of the architecture and construction treatise. For the second proportion (A − B = 0), the average value obtained is very close to zero, which shows equality between the two sides of the towers, an issue also indicated by the architecture and construction treatise. Finally, for the third relationship (e = A/4), the average value obtained of 1.23 m is also very close to the average value obtained for e (1.19 m), which shows a possible relationship, again in this case, as reflected in the Treatise of Architecture and Construction.

Figure 8 shows the dimensions of the variables e, A, and B and the proportions A/4 and H/4. The inclusion of the variables H and A-B has been omitted to improve the clarity of the Figure. As can be seen, all the thicknesses of the walls of the body of the tower (e) are close to a quarter of its width (A/4). However, it can be seen that there are two towers (10 and 12) where the proximity between these two parameters is less pronounced. These two towers belong to towns created in the 18th century by the Murcian Cardinal Belluga y Moncada in the colonisation process of the Pious Foundations (San Fulgencio and Dolores). Then. considering the dimensions of the tower parallel and perpendicular to the facade (A, B), we verified that there is mostly equality; only in towers 8, 13, and 14 does the rule seem unfulfilled. Lastly, the proportion A = H/4 is shown on the graph in practically all cases, except for tower 6, where there is a noticeable difference.

Continuing with the data analysis, from a descriptive point of view, Figure 9 shows the histograms of the variables subject to analysis (H, A, B, e). As can be seen, the normal curve has been superimposed on the histograms (black line), showing that the distribution of the data does not seem to show normality, insofar as its frequency distribution does not fit the normal curve. This circumstance, together with the small sample size (n = 15), makes it necessary to use non-parametric analysis techniques [19] since not being able to apply the central limit theorem (due to the small sample size), or the lack of normality of the data, are some of the hypotheses necessary to be able to use parametric tests.

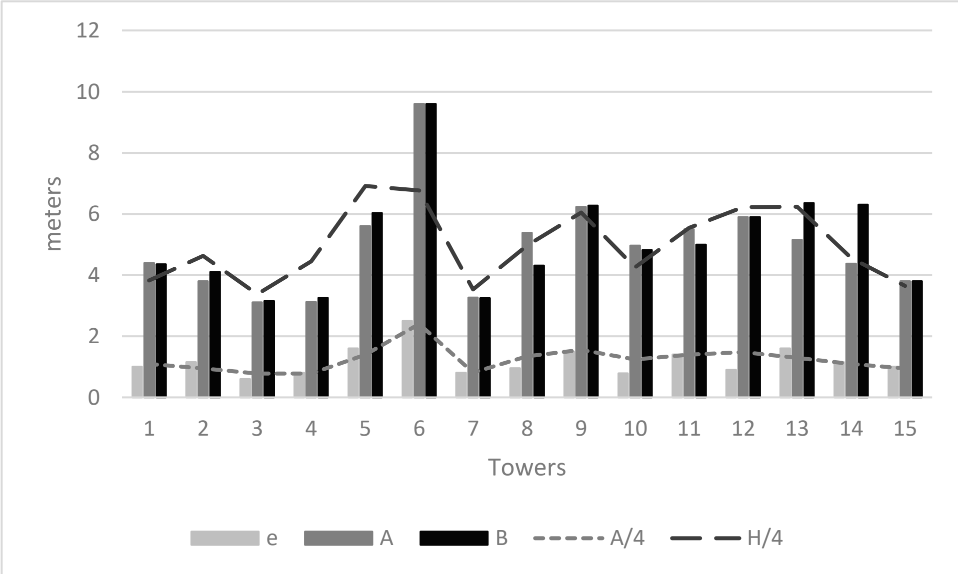


Figure 8. Dimensions and proportions of the towers.

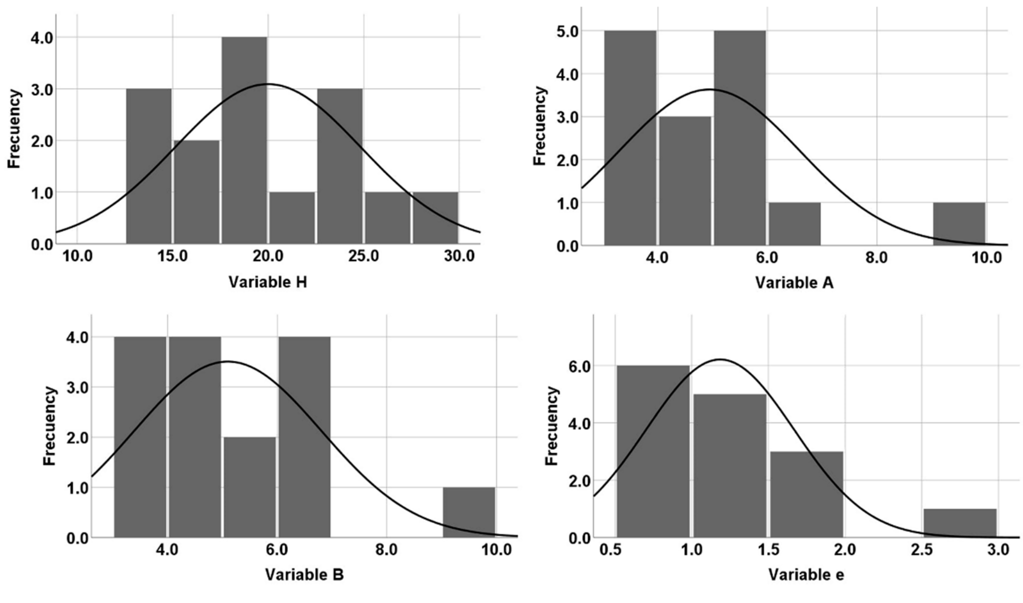


Figure 9. Histograms of the variables and normal curve.

Once the existence of possible relationships between the analysed data was detected, the next step in the analysis was to study whether the observed relationship was significant. For this, the non-parametric correlation between the variables studied was calculated. The results obtained (Table 4) showed a strong relationship between the variables, with a correlation greater than 0.65 in all cases and with high significance. In the fieldwork phase, during the data collection for the towers, it was observed that the measurement of the width of the tower parallel to the façade (A) and that of its perpendicular (B) did not coincide. However, as seen in the descriptive values, on average, their difference was close to zero (2 cm) and the value obtained for the correlation was very high (0.803 **), which may show that the differences observed during data collection were not very consistent. As expected, the height of the tower (H) and thickness of the wall (e) were also strongly related (0.781 **), as well as the height and dimensions of the base of the tower (0.842 ** and 0.811 **).

Table 4. Non-parametric correlation (Rho de Spearman).

	H	A	B	e
	1.000			
A	0.842 **	1.000		
B	0.811 **	0.803 **	1.000	
e	0.781 **	0.657 **	0.787 **	1.000

** Correlation is significant at the 0.01 level (bilateral).

Once the existence of a significant relationship between the dimensions studied was outlined, next, we assessed whether or not the guidance established by the architecture and construction treatise (Table 2) was met in the towers studied. For this analysis, three non-parametric hypothesis tests were performed, using the Kruskal–Wallis test for independent samples [18]. This test allowed us to check whether the difference between the medians of the variables studied was statistically significant. The hypotheses that we tested were those specified in Table 5.

Table 5. Contrasting hypotheses of the analysed proportions.

Geometric Characteristics Treated	Contrast
A = H/4	H_0: Med($H_1/4$) = Med($H_2/4$) = … Med($H_{15}/4$) H_1: at least one is different
A − B	H_0: Med($A_1 - B_1$) = Med($A_2 - B_2$) = … Med($A_{15} - B_{15}$) H_1: at least one is different
e = A/4	H_0: Med($A_1/4$) = Med($A_2/4$) = … Med($A_{15}/4$) H_1: at least one is different

As can be seen, the null hypothesis (H0) indicated that the population medians were all the same, while the alternative (H1) indicated that at least one pair (i, j) was different. To apply this test, a grouping variable was generated. This variable grouped the towers according to the construction period so that the selected periods had an amplitude that was as similar as possible within the three chosen grouping ranges (Table 6).

Table 6. Grouping by construction period.

Grouping Variable	Tower	Construction Period (Years)
1	1 2 3 4 5	<1700–1730
2	6 7 8 9 10	1740–1760
3	11 12 13 14 15	1770–1790

Table 7 shows the result of the Kruskal–Wallis test for the three contrasts carried out, considering the grouping of the towers in the three periods indicated above. If significance was observed in the three cases, the value obtained exceeded 0.05 ($p > \alpha$). This means we could not reject the null hypotheses of the contrasts, and so we concluded that the population medians of the proportions obtained for the towers did not differ. Therefore, we can assert that in the case studies, the construction and design criteria that marked the reference treatise were met.

Table 7. Kruskal–Wallis test for a grouping of towers in three periods.

	H/4	A − B	A/4
Kruskal-Wallis H	0.620	3.525	2.950
Asymptotic sig.	0.733	0.172	0.229

To investigate whether the grouping carried out had any effect on the result, the contrasts were performed again, but on this second occasion, a grouping variable of two construction periods was defined. We distinguished towers built before 1750 (1 to 8) and from 1750 to 1790 (9 to 15). The result of the Kruskal–Wallis test is shown in Table 8, and as can be seen, the interpretation, given that $p > \alpha$ is the same as in the previous case, gives greater robustness to the contrast performed.

Table 8. Kruskal–Wallis test for a grouping of towers in two periods.

	H/4	A − B	A/4
Kruskal-Wallis H	0.335	0.013	1.211
Asymptotic sig.	0.563	0.908	0.271

4. Discussion

This work analysed the geometry of 15 towers belonging to churches built during the last third of the 17th and the 18th century. All the analysed churches are located in the province of Alicante (Spain), specifically in the region of Bajo Segura. During fieldwork and data collection, differences between the measurements and proportions taken from the towers were revealed. Analysis of the Treatise of Architecture and Construction before the 18th century revealed that the design and construction of these buildings should have met a series of proportions, but at first, for some of the analysed churches, these seemed not to have been met. Once fieldwork was complete, the data we collected were treated statistically to determine whether or not the differences found could be generalised or whether they were isolated differences. Descriptive analysis of the variables and proportions pointed in the direction of the Treaties, showing that, on average, the towers' proportions followed the established guidelines. Subsequent analysis of the correlation between the variables revealed that the dimensions of the towers (e, H, A, and B) were greatly related, and that this relationship was highly significant. This result and the significance found allowed us to propose that the towers analysed were built under the guidelines of the Treatise of Architecture and Construction. To test whether the relationships found between the proportions were spurious, or on the contrary, the result of the methodical work of the builders of the time, we ran a non-parametric test twice according to the proportions marked by the treatise [14,15,20]. On the first occasion, we defined a grouping variable for three construction periods: from before 1700 to 1730, from 1740 to 1760, and from 1770 to 1790. These three periods were selected arbitrarily but with roughly even durations and to contain all the analysed churches. The results of the contrasts were conclusive: in none of them could the hypothesis of equality of medians of the proportions be rejected. This implied that the population medians of the proportions of the churches coincide, meaning they all follow the pattern set out in the treatise. The selection of periods was then done a second time to check whether the period influenced the result of the contrast. On this second occasion, two construction periods were chosen, one before 1750 and the other from 1750 to 1790. The decisions derived from the results of the contrast were the same as before, showing that grouping the temples in one way or another did not influence the contrast.

The results we obtained showed significantly that despite the churches analysed being built over almost 100 years, the geometric rules set out in the Architecture and Construction Treatise were followed. These rules were passed down from generation to generation, allowing churches built a century later to maintain the same proportions. Hence, why a standard bell tower that corresponds to certain geometries and possesses common attributes can be found within the temporal and spatial scope studied.

Concerning the urban and territorial incidence, the concentration of bell towers in the Bajo Segura region is based on the population and colonisation. The construction of religious buildings in new places, as well as the conversion or adaptation of old temples to Christian buildings, was conditioned by the characteristics and history of the area where they were built. During the 18th century, this area was managed by a wide range of landowners, with supreme jurisdiction in King Alfonso's time, characterised by secular, ecclesiastical, and abbatial estates [21–25]. They approached culture and construction in a repopulating social panorama, which led to the construction of bell towers with the same function and architectural composition.

The studied bell towers represent the main communication routes available in the region during the 18th century.

The spread of the population, the area's progressive occupation, its economic strength, and the religiosity of its inhabitants [26,27] determine the compositional characterisation and dimensions of a bell tower, as well as the height from which it begins to rise, but always under common proportions.

This research on the pre-established patterns for the design and construction of bell towers during the 18th century in Bajo Segura is not a closed study. Instead, it opens up the possibility of future research that analyses these architectural elements. Bell towers have a singular form with a certain geometry and construction, as analysed in this article. However, there are other possible opportunities for research, for instance, on the relationship between the bell tower and the building, the different techniques used, and the social and religious connotations that characterise the bell tower in Western religious architecture.

5. Conclusions

The geometry of 15 bell towers belonging to Christian churches located in the Bajo Segura region, in the province of Alicante, Spain, was analysed to establish a bell tower pattern whose main geometric characteristics maintain the proportions established in the Treatise of Architecture and Construction of Fray Lorenzo de San Nicolás and in that of Atanasio G. Brizguz. To carry out the analysis, fieldwork was carried out in which images and dimensions of the 15 bell towers visited were compiled. At first, some differences were observed between the dimensions of the towers, which led to the suspicion that the guidelines established by the Architecture and Construction Treatise might not have been met in the study area. Yet, later analysis revealed that the dimensions of the towers were highly significantly related and that the proportions that marked the treatise were fulfilled. This result was contrasted using non-parametric techniques and we concluded that the population medians of the proportions analysed in the studied towers did not differ. This result is highly significant, as despite the analysed period covering more than a century, a geometric pattern marks the construction of these towers. This pattern was transmitted from generation to generation, meaning that a century after the first analysed towers were built, the proportions established in the treatise continued to be maintained. Eighty percent of the bell towers have a height equal to four times their width. The average height is 20 m, the exterior width is 5×5 m, and the thickness of the walls is 1.20 m. We have been able to establish a bell tower pattern whose main geometric characteristics maintain the proportions established in the Treatise of Architecture of Fray Lorenzo de San Nicolás and in that of Atanasio G. Brizguz for the design and construction of a bell tower.

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References

1. Azanza López, J.J. Tipología de las torres campanario barrocas en Navarra. *Príncipe de Viana* **1998**, *59*, 333–392.
2. Chamorro Trenado, M.A. Los campanarios góticos de las comarcas gerundenses: Tipologías y sistemas constructivos. In Proceedings of the Actas del Sexto Congreso Nacional de Historia de la Construcción, Valencia, Spain, 21–24 October 2009; Instituto Juan de Herrera: Madrid, Spain, 2009; Volume 1, pp. 329–338.
3. Lamas Domingo, A.; Mañes Baguena, J.V.; Moreno Rodríguez, P.; Rico Llopis, A.; Rubio Rodríguez, F. Preliminary study to the restoration of the Tower Keep in Jérica (Castellón, Spain). In *Rammed Earth Conservation, Proceedings of the First International Conference on Rammed Earth Conservation, Restapia, Valencia, Spain, 21–23 June 2012*; CRC Press/Balkema: Boca Raton, FL, USA; pp. 303–308.
4. Salinas Robles, S. La arquitectura religiosa en el s. XVIII. *Oleana: Cuadernos de Cultura Comarcal*. 2009, Volume 24. Available online: https://dialnet.unirioja.es/revista/13163/A/2009 (accessed on 21 February 2021).
5. Vidal, F.J. Los campanarios valencianos de la segunda mitad del S. XVIII, (Parte II). *TC Trib. Constr.* **2000**, *8*, 60.
6. Juan Vidal, F. *Los Campanarios De José Mínguez: Valencia, 1700–1750*; Ediciones Generales de la Construcción: Valencia, Spain, 2000.
7. González Bueno, A. Reflexiones en tomo a los viajes de A. J. Cavanilles por tierras de Valencia (1791–1793). *Asclepio Rev. Hist. Med. Cienc.* **1995**, *47*, 137–167. [CrossRef]
8. Cavanilles, A.J. *Observaciones Sobre La Historia Natural, Geografía, Agricultura, Población y Frutos del Reyno de Valencia*; en Madrid en la Imprenta Real: Madrid, Spain, 1797; Volume II. Available online: https://books.google.es/books?id=ZfhcAAAAcAAJ&printsec=frontcover&hl=es&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false (accessed on 21 February 2021).
9. Ruggieri, S.; Tosto, C.; Rosati, G.; Uva, G.; Ferro, G.A. Seismic vulnerability analysis of Masonry Churches in Piemonte after 2003 Valle Scrivia earthquake: Post-event screening and situation 17 years later. *Int. J. Archit. Herit.* **2020**, 1–29. [CrossRef]
10. Casolo, S.; Diana, V.; Uva, G. Influence of soil deformability on the seismic response of a masonry tower. *Bull. Earthq. Eng.* **2016**, *15*, 1991–2014. [CrossRef]
11. Ivorra, S.; Cervera, J.R. *Caracterización Estructural de Una Torre-Campanario del Siglo XVIII a Través de Ensayos Dinámicos*; Actas del VIII Congreso Nacional de Propiedades Mecánicas de Sólidos: Gandía/Valencia, Spain, 2002; pp. 563–569.
12. Borromeo, C.; de Estrada, G.; Elena, I.; Reyes Coria, B. *Instrucciones de la Fábrica y del Ajuar Eclesiásticos*; Estudios y Fuentes del arte en Mexico; Universidad Nacional Autónoma de Mexico, Ciudad Universitaria: Ciudad de Mexico, Mexico, 1985; Volume 49, p. 113.
13. Pingarron Seco, F. *Las Advertencias Para Los Edificios y Fábricas de los Templos del Sínodo del Arzobispo de Valencia Isidoro Aliaga en 1631: Estudio y Transcripción*; Asociación Cultural "La Seu", D.L: Valencia, Spain, 1995.
14. De San Nicolás, L. Arte y Uso de Arquitectura: Primera Parte. 1639. Available online: http://www.sedhc.es/biblioteca/tratado.php?ID_pubD=27 (accessed on 12 January 2020).
15. Brizguz y Bru, A.G. Escuela de Arquitectura Civil, en Que se Contienen Los Órdenes de Arquitectura, la Distribución de Los Templos y Casas y el Conocimiento de los Materiales. 1738. Available online: http://www.sedhc.es/biblioteca/tratado.php?ID_pubD=36. (accessed on 12 January 2020).
16. Alepuz Chelet, J.; Espadas Maciá, S. Inventario General de Campanas de la Comunidad Valenciana Por Poblaciones. Available online: http://campaners.com/php/valencia.php (accessed on 12 January 2021).
17. Martín Martín, Q.; Cabero Morán, M.T.; de Paz Santana, Y.D.R. *Tratamiento Estadístico de Datos Con SPSS: Prácticas Resueltas y Comentadas*; Thompson: Madrid, Spain, 2008.
18. Newbold, P.; Carlson, W.L.; Thorne, B.M. *Estadística Para Administración y Economía*; Pearson: Madrid, Spain, 2013; p. 852.
19. Gómez-Biedma, S.; Vivó, M.; Soria, E. Pruebas de significación en Bioestadística. *Rev. Diagn. Biol.* **2001**, *50*, 207–218.

20. Fornés y Gurrea, M. Observaciones Sobre la Práctica Del Arte De Edificar. 1841. Available online: http://www.sedhc.es/biblioteca/tratado.php?ID_pubD=17 (accessed on 12 January 2020).
21. Canales Martínez, G.; Gil Olcina, A. *Residuos de Propiedad Señorial en España*; Universitat d' Alacant (Publicacions): Alicante, Spain, 2007; p. 2.
22. Bonmatí Antón, J.F.; Crespo Rodríguez, F.; Gómez López, J.D.; Palazón Ferrando, S.; Salazar Vives, J.; Segrelles Serrano, J.A. *El Bajo Segura: Estructura Espacial, Demográfica y Económica'*; Universidad de Alicante: Alicante, Spain, 1995.
23. Canales Martínez, G.; Salazar Vives, J.; Crespo Rodríguez, F. Proceso de formación urbana de Orihuela (Alicante). *Investig. Geogr.* **1992**, *10*, 143–164. [CrossRef]
24. Canales Martínez, G.; Martínez García, I. *El Señorío Eclesiástico de Bigastro (Siglos XVIII–XIX)*; Instituto de Cultura "Juan-Gil Albert": Alicante, Spain, 1994.
25. Canales Martínez, G.; Ruiz Segura, E. La Huerta del Bajo Segura (Alicante), un patrimonio cultural en peligro. Reflexiones sobre un proyecto museológico integral. *Investig. Geogr.* **2011**, *54*, 205–248. [CrossRef]
26. Canales Martínez, G.; Vera-Rebollo, J.F. Colonización del cardenal Belluga en las tierras donadas por Guardamar del Segura: Creación de un paisaje agrario y situación actual. *Investig. Geogr.* **1985**, *3*, 143–160. [CrossRef]
27. Canales Martínez, G.; Gil Olcina, A. Consolidación de dominios en las Pías Fundaciones del Cardenal Belluga (Bajo Segura). *Investig. Geogr.* **1987**, *5*, 7–26.