Publicado en: Salemi, A.; Sánchez Rivera, J. I.; Mondello, A. y Sáiz Virumbrales, J. L."The collapse of the tower of Valladolid Cathedral and its controversial relationship with the 1775 Lisbon Earthquake". Conference Proceedings SER 4SC Seismic and Energy Renovation for Susteinable Cities. Monfalcone (Gorizia): EdicomEdizioni. 2018. ISBN: 978-88-96386-56-9, pp. 233-245.

SER 4SC

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES
CONFERENCE PROCEEDINGS

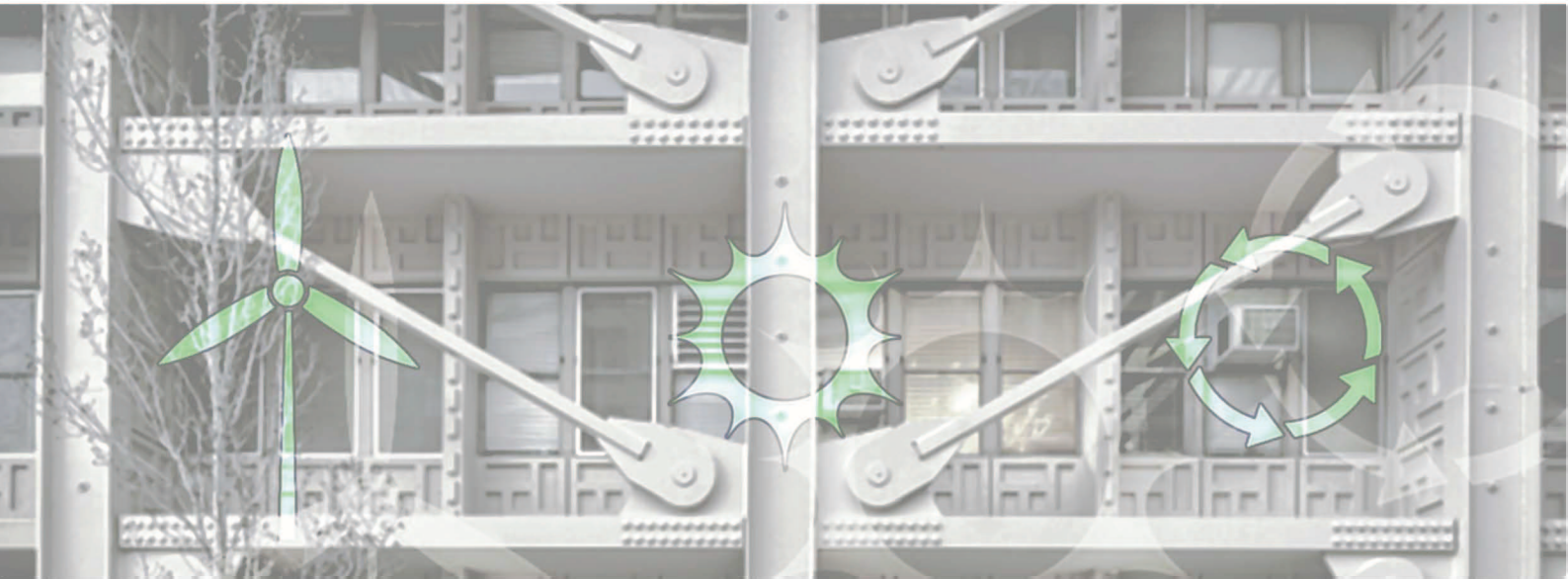
1st to 3rd February 2018
University of Catania
Department of Civil Engineering and Architecture

EDITORS
Giuseppe Margani
Gianluca Rodonò
Vincenzo Sapienza

EdicomEdizioni

DICAR
Dipartimento Ingegneria Civile e Architettura

UNIVERSITÀ degli STUDI di CATANIA



Published by EdicomEdizioni

Monfalcone (Gorizia)
Tel. 0481 484488
Fax 0481 485721
e-mail info@edicomedizioni.com
www.edicomedizioni.com

ISBN 978-88-96386-56-9

The Collapse of the Tower of Valladolid Cathedral and its Controversial Relationship with the 1755 Lisbon Earthquake

Angelo Salemi[a], José Ignacio Sánchez Rivera[b*], Attilio Mondello[a], Juan Luis Sáiz Virumbrales[c]

[a]*Departament of Civil Engineering and Architecture – University of Catania, via Santa Sofia 64, 95125 Catania, Italy*
[b]*University of Valladolid, School of Architecture, Avda. de Salamanca s/n, 47014 Valladolid, Spain*
[c]*Architect-MA in Architectural Restoration and Conservation, Plaza de Madrid 2, 47001 Valladolid, Spain*

Abstract

The 1755 Lisbon Earthquake was a catastrophic event for the Portuguese capital and it was violently perceived even in the western half of the Iberian Peninsula. Traditionally, to this seismic event are recognized several buildings damages in Castile and Leon.
In this paper, we analyse the damages that could have occurred in the centre of the region, starting from the reports issued by local governments explaining the extent of the earthquake perception. The study will focus on the Valladolid Cathedral and its bell tower; the latter fell in 1841 and its collapse has been attributed to the Lisbon Earthquake of 86 years earlier.
However, the analysed documentation (some of it previously unpublished) shows that the tower conditions were poor before the earthquake. The structure underwent repairs since its construction to improve its stability. In the 1740s, some architects as Fray Pedro de la Visitación and Antonio San José Pontones worked and made reports on the tower. In 1755, the Lisbon Earthquake was clearly perceived within the cathedral. After this event, the tower was affected by an important repair action by the academic architect Ventura Rodríguez. The repairs did not improve the problems already encountered before the earthquake, especially regarding damages caused by rainwater infiltrations. For these reasons, the collapse of 1841 cannot be attributed only to the seismic effects of the Lisbon Earthquake.

Selection and peer-review under responsibility of SER4SC2018 Scientific Committee.

Keywords: Valladolid; Cathedral; Tower; Collapse; Lisbon-Earthquake; Masonry-construction.

1. Introduction

Valladolid, a city located in the centre of the "*Comunidad Autónoma*" of Castile and Leon, 200 kilometres north of Madrid, had no cathedral until later dates, 1595. Juan de Herrera, architect of King Philip II, designed a large building as a major church, of which less than half could be built, given the crisis suffered by Castile for much of the 17th century, together with the chronic income shortage suffered by the Valladolid Cathedral Chapter; as a result, the current Cathedral was paid primarily with the sales

* José Ignacio Sánchez Rivera. Tel.: +34-983 425 261
E-mail address: jignacio@arq.uva.es
English version by Nieves Saiz Montes.

income of a primer for educating children whose monopoly was granted by Philip II to the cathedral chapter. As for the towers provided by Herrera, only one could be built, which collapsed in 1841.

This tower in particular, its pathology and its relationship with the Lisbon Earthquake is the object of this paper. Since the end of the 19th Century, its collapse has been attributed to either the effects of the Lisbon Earthquake [1] or to failures in the building's foundations [2]. Until now it was known that the tower had undergone repairs in 1726 [3] and in 1746 [4], although the scope of the latter and the reports that it generated, before the earthquake, came to light with the present paper. It was understood that the tower received reinforcement between 1761 and 1764 and that it experienced new repairs at late 18th and early 19th Centuries. Moreover, in the present paper, the data provided on the reports from the architects and military engineers brought about by the collapse in 1841 has finally come to light. Arranging all this documentation together, we can give a pathological account of the tower and its interventions, to be in a better position to make a technical approach to its problems; this will be combined with the knowledge of the effects of the Lisbon Earthquake in the region.

The authors have made a virtual model of the entire tower at the time of the earthquake, in order to establish hypotheses. To do this, the current remains have been measured and the walls' surfaces have been drawn using flat photogrammetry. Finally, a study of its statics has been made graphically.

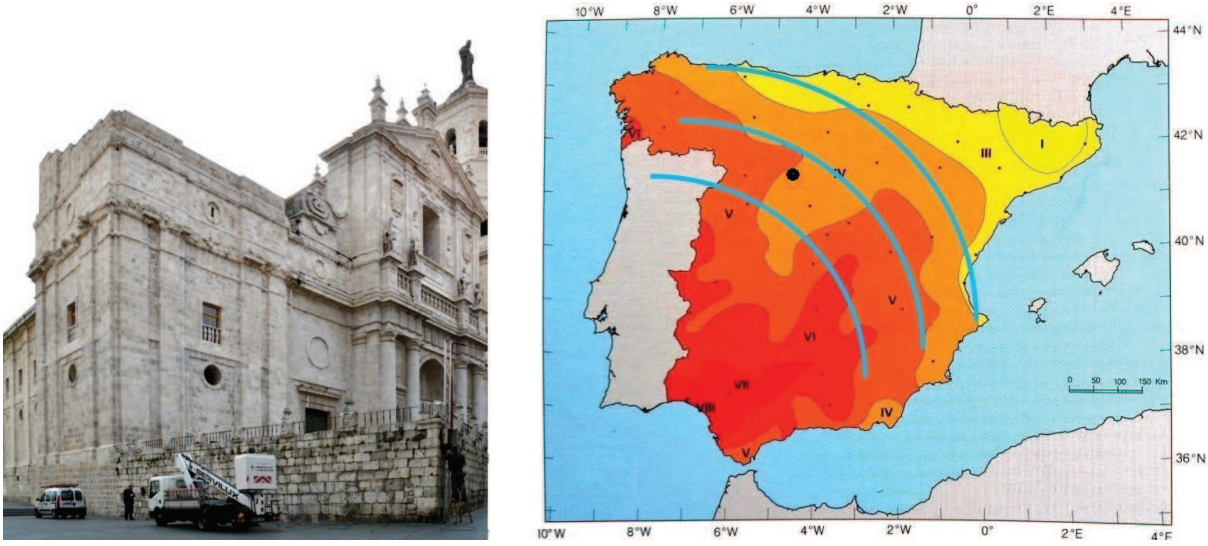


Fig. 1. (a) On the left: The remains of the fallen-down tower of the Cathedral of Valladolid at its present state. (b) On the right: Map of Peninsular Spain with the isoseismic lines of the 1755 Lisbon Earthquake. Valladolid's position in denoted by the heavy black point.

2. The Lisbon Earthquake

On November the 1st, 1755, there was a strong earthquake about 200 km. West of Cape San Vicente, which was sensed on the Iberian Peninsula, particularly in the City of Lisbon, where the earthquake generated a subsequent tsunami, devastating a major part of the city. Due to these effects, it is known as "The Lisbon Earthquake". However, the impacts were also felt with great intensity in inland Spain [5]. In recent studies, the epicentre has been located at coordinates 36º 30 'N, 10º 00' W, and at a depth between 20 and 40 km. approximately. The local time was around 9:16 am.

King Ferdinand VI moved hastily from El Escorial to Madrid after feeling the earthquake, ordering the Council of Castile to carry out an eight-question survey, directed to the parishes. The information collected is kept in the Spanish National Historical Archive (AHN) and has served to evaluate the degree of intensity in the European-Macroseismic Scale-EMS, 1998 on the surface of the Iberian Peninsula.

The testimonies collected in the aforementioned survey refer to the noise heard inside the temples, which caused panic among the parishioners attending All Saints' Day Mass, although there were no serious effects on the area, except for the fall and breakage of one little portion of the tower of Ampudia Collegiate-Church (in the neighbour Province of Palencia) on the temple roofs.

The analysis of the intensity of the earthquake on Spain, scale EMS - 1998 (with 8 levels) [6], allows us to establish that the isoseismic line between levels IV and V include a large portion of the Castile and Leon plain at the zone of intensity IV, which could be caused by the sedimentary nature of the centre of the region. This would explain the inclusion of Valladolid within the intensity zone IV, although, due to its geographical proximity to both the epicentre and the City of Lisbon, the expected effects should have been higher (fig. 1b).

3. The construction of the Cathedral of Valladolid and its tower

At the end of the 11th Century, Valladolid had a collegiate chapter with a church as headquarters. The primitive Romanesque building was replaced in the first half of the 13th Century by a Protogothic one. However, the increasing importance of Valladolid in the late Middle Ages and the principles of the Modern era, led to the construction of a new church, which would be the third that the chapter occupied. This began in 1527. This church did not follow the canonical orientation but a North-South axis (the main facade to the South), as they had to use a difficult inclined terrain owned by the chapter. We have two partial plans from this temple [7], so we know the layout of part of the main façade end, following late-Gothic style, with three naves, plus another two aisles with side chapels, where, on their last bay, two main towers would rise. However, little was constructed when by 1580 Juan de Herrera drew up new plans for a church, the fourth Collegiate Church, which became a cathedral in 1595.

According to the architect and historian Fernando Chueca-Goitia, the Herrerian project owed much, in its configuration in plan, to the Collegiate-Church began in 1527 and the towers foreseen by the great Cantabrian architect were also placed in the same place, at the sides of the main façade to the South. The Classicist Herrerian project also had three naves, with a central transept and a square apse surrounded by other two shorter towers finished in spires.

The elevations of the front towers designed by Herrera are closely linked to the equivalent of the El Escorial Basilica (fig. 2). They are a finished model of a Mannerist tower design. Each one would be approximately square in plan, with four bodies separated by powerful entablatures: the two lower ones were solid and only had small windows and round vents; the firsts two side chapels of the church would be located in the interior of its lower bodies. The third body had a composition in the shape of an arch of triumph in its four fronts. The last body consisted of a dome on a drum with a lantern, finishing off the piece. Herrera's drawings are not very explicit as to the way of communicating in height of the tower, because he only drew a plan of the towers, the ground floor one, with the chapel and a return staircase.

The construction of the Herrera cathedral was started by the southwest side and, after several decades working throughout crisis and difficulties, in 1668 the section from the transept to the main facade had been built using stone, although the vaults were made of brick. It was closed with a provisional brick wall, which still lasts. The cathedral, thus adapted for its use, was consecrated in that year and throughout the following half century various elements were made, such as the collapsed tower (object of our study) and the upper part of the main façade, completed in 1733. From that year, the work of the cathedral hardly moved on. The great socio-political instability of the first half of the 19th Century, together with the Mendizábal's Confiscation (1835) left the Spanish Catholic Church without economic capacity to face the expensive completion of the building. When the tower collapsed in 1841, the building was left without a bell tower until the current one was built, with economic difficulties again, between 1879 and 1890. Finally, in the 1960s, the lower body of the façade of the Epistle-side transept was made.

The bibliography is not clear about when exactly the collapsed tower was built. For Chueca-Goitia, its erection was during the middle of 17th Century [8], but for art-historian J.J. Martín-González, it happened

on early 18th Century [9]. Manuel Canesi, a local historian from the 18th Century, said that the bells had been placed in the tower in 1706, when it had become completed, and that before this, it had been mid-built [10].

Certainly, the documentation of the cathedral is not clear in this regard: the accounts of "*Obra Nueva*", reflecting the book-keeping of the building process, are little explicit during the second half of the 17th and the beginning of the 18th Century. To make things harder, the tower of the Medieval Collegiate Church remained in use for much of this period and the repairs are noted in the same documentation: sometimes it is not clear whether the works refer to the old tower or to the erection of the new one.

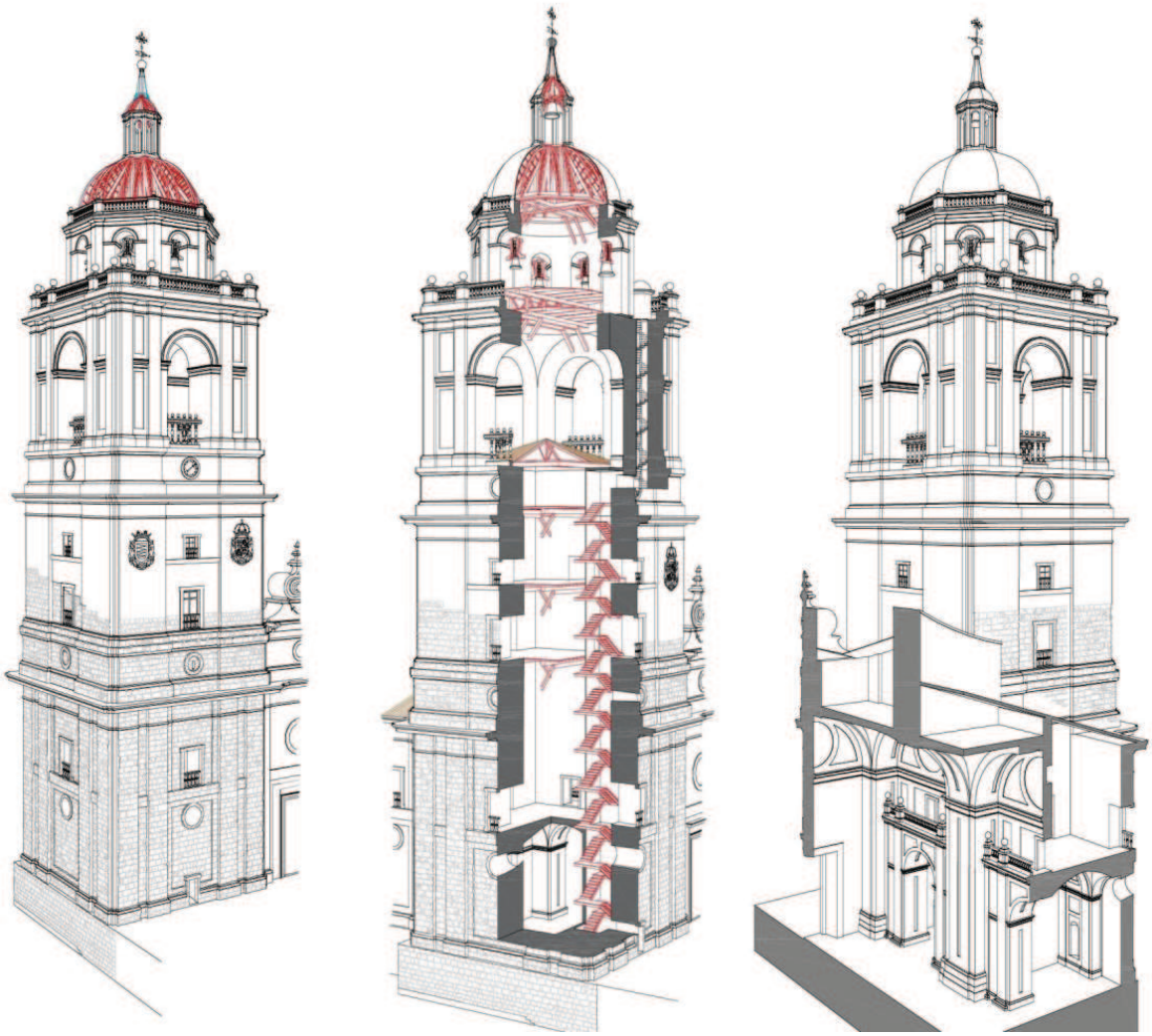


Fig. 2. Restitution of the tower. On the left, view from the Southwest; the dome shows its internal wooden structure, without its slate pieces surface. On the centre, section of the tower displaying its internal layout and staircases. On the right, view from the Northeast, showing the relation of the tower with the aisle and side chapels. Drawings by the authors.

In 1667 the doors of the two tower chapels are mentioned, meaning that the lower body would already be well ahead. In 1670 it appears that the rooms for the bell ringers were started, which implies that the lower body would be completed and that the second body was perhaps well ahead, as it was where the rooms of the bell ringers were located. At the beginning of 1675, the staircase was paid for and the

following year reflects the expenses for three books of architecture "*to choose the style to close the tower*". Presumably it would be a provisional roof to finish the part of the tower already built. From then on, no more works were recorded in the bell tower until the beginning of the following century. It seems that at the beginning of 1705 the works were resumed, when the Masters Misa and Cueva were paid to remove the roof and bring stone. At the end of the year, it is mentioned that the last cornice had been placed. In October 1706 there are invoices to place the bells in the new tower and in December to do the same with the clock that told the time to the citizens and was maintained by the City council together with the Cathedral chapter. Finally, in July 1707, there are payments for iron pieces of the dome. As of 1708 there are no more pays for work materials in the accounts of "*Obra Nueva*", so we can pretend the tower as completed [11].

Juan de Herrera's designs for the tower were altered during its construction, we rather think for functional reasons (fig. 3b): the tower had to house the clock and, in its upper part, the bells. Herrera had not made space for the dial, which was done by hypertrophying the podium of the third body of the tower. Perhaps to maintain the proportions in some way, the double pilasters of the second body were transformed into wide simple pilasters, to place the Royal and City Shields. The entablature that finished the third body, acquired greater heaviness following Baroque fashion, diminishing the great arches underneath. On the other hand, Herrera probably had thought to place the bells in a wooden structure inside the third body, which with its large openings would have allowed the expansion of sound; notwithstanding, the Spanish Baroque tendency demanded great turning around bells. So, to arrange them this way, an octagon body was added, with arches for the bells, replacing the dome's low drum that, apparently, Herrera had thought to top off his main towers.

With reference to the internal organization of the tower, there is little data. It seems logical that to each level of windows would correspond a floor, directly above the vault of the lower chapel the first one and with a wooden structure the others; we have also assumed that there would be another floor for the clock chamber, cited in the documentation, with the same characteristics as the wooden others. Under the arches of the third body (known as "*the four winds*") there surely was a roof, reflected in the model of the completed cathedral made at the end of the 18th Century [12] and we think that it is also present in a sketch on which a receipt was written for a payment for the installation works of Ventura Rodríguez's reinforcement, which will be discussed later [13]. In the last body, for the bells chamber there was another wooden floor which we know about for its repairs [14]. For the restitution of the tower we made, we have added another superimposed floor to access the bells, as seen in other towers that mimic the one we are studying, as is the case of the one of San Andrés Church in Valladolid. The communication would be made by a wooden straight staircase up to the clock chamber level, then changing to a spiral staircase reflected in the plans of the tower made by Ventura Rodríguez [15], which would ascend by one of the pillars from the body of the four winds to the bell room (fig. 2). The layout of the stairs is also demonstrated in the aforementioned 18th Century model of the cathedral.

4. A troublesome tower

A few years after its conclusion, the tower began to give problems on its crown. On July 18th, 1726, the prestigious Benedictine architect Fray Pedro Martínez de Cardeña signed a report on how to deal with the important leaks of the tower's dome. According to him, these were due to its bad construction; he said that the "surfaces of the dome" were made of small pieces of masonry, the water entered and frost aggravated the problem. The solution he devised was to dismantle the dome surface and build a new one with Campaspero stone slabs (very compact limestone) assembled in such a way that the water infiltration was avoided. He proposed to make, also with Campaspero stone, a cornice that embraced the lowest part of the dome on the outside, to prevent the water from falling down licking the lime from the joints. On the floor of the corridor, under the sill that topped the tower's octagon, he planned to place a gutter to help collect the waters, which would be expelled by eight gargoyles, presumably one in each vertex of the

octagon. Master Matías Machuca, one of the best local architects of the moment, was in charge of the realisation of this project [16]. However, those eight gargoyles are not shown on the drawings of the tower (even on the best quality ones, made by Ventura Rodríguez).

In any case, the tower's filtration problems were not solved. Towards 1740, the leakage must have been serious, as the chapter requested a series of reports to different architects which culminated in the reconstruction of its crown.

The earliest one was made by Antonio Pontones, one of the most notable architects of the region in the mid-18th Century. His report, dated in Valladolid on April 3rd, 1740, is quite large. In first place he says that the cause of problems in buildings lies in two issues: the quality of construction and the effects of time. For Pontones, in this first approach, the entire tower, except the dome, was well built. He denounced the presence of cracks, but they do not seemed problematic for him, because he said that they were common in such buildings and that they were stable. As for the last body, he said that he had not seen failures, although he saw cracks in the dome, which seemed to him caused by the variety of types of stone in its walls. Pontones recommended dismantling the dome's masonry outer cover, leaving "*its helmet*" naked and build on it another dome made of pieces of good quality stone, tongue-and-groove jointed, so that the water could not permeate and the dome would also be lighter; he advised not to cover it with materials such as slates, as for, according to him, they would take off the beauty from an all made of stone tower [17]. The similarity of his proposal with the one Fray Pedro Martínez made 14 years earlier makes us suspect that possibly the latter was not carried out. Seeing Pontones data, we can think that the problematic dome was made with an inner leaf in the shape of a half-orange that held a masonry coating shape of an octagon outside, in a way like the different drawings of the tower we can access.

The chapter would seek a second opinion, as there is another report, this time from José de la Calle, Master of the Royal Palaces of La Granja de San Ildefonso and Valsaín, who in previous years had made two designs for the tower of El Burgo de Osma Cathedral, one of which succeeded [18]. This short document, dated in Valladolid on May 16th, 1740, announced instead the decay of the dome that covered the tower and, although he declared that this collapse was not immediate, he did not see its repair possible. The cause, he said, was its bad construction and the little knowledge of the mason who created it; on the other hand, he reflected that the tower had leakages not only in the crown, but in lower parts too, such as the pendentives (presumably he would refer to those existing on the four large arches of the third body to link the upper octagon), therefore he recommended to place lead plates on the surfaces where the rainwater falls to ensure the conservation of the rest of the walls [19].

As de la Calle had predicted, the ruin was increasing and the first days of 1743, several pieces of the inside of the dome were detached, causing the logical alarm of the chapter. Gathered the 4th January, they determined that Antonio Pontones had to examine the tower again. He declared that it was necessary to shore the dome up with a wooden frame urgently to give the chapter time to decide the most convenient solution. The frame was made by Pontones himself [20].

The chapter looked for new reports to decide what to do with the tower.

The Franciscan architect from Salamanca, Fr. Francisco de la Visitación, produced an extensive document dated in his city on June 22nd, 1743. He began with the cracks he had seen in the tower, particularly one that started at its low door and kept to the top end, branching off the facade. He saw similar cracks on the facade to the West. All this made him recommend that the weight of the new crown built in the tower to be very tight. He criticized the ruined dome and the octagon body for its little slenderness, which in his opinion gave the appearance that the tower lacked a top body. He proposed three possible solutions: The first would be to demolish the ruined dome and, alter removing three courses of stones from the octagon body to eliminate weight, place on it a more pointed and slender dome, made of stone, and built in such a way that would prevent the entrance of water, placing on top of this dome the same lantern that topped the ruined one. The second solution was to demolish the dome and build a wooden spire on the octagonal body, imitating in its exterior an also pointed dome, an option that he recommended as it was a light coronation and removed weight; the third option was to dismantle dome

and octagon and, following the primitive design of Juan de Herrera, raise a drum and, above it, the new dome, also pointed and with a lantern provided. Finally, to strengthen the lower bodies, he defended to wall those windows in which it was possible or, in those that could not be closed by their use, reduce them in size and sew them by means of iron bars [21].

On August 13th, 1743, an architect of the Council of Castile, Juan Esteban, signed his report in Madrid, apologising to the chapter for his delay. This is undoubtedly the most radical of all: He defended dismantling not only the dome and the octagon, but even the body of the four winds, built, according to him, with too wide arches, which loaded the corners of the tower and not the centre of its walls, producing differential efforts; the body of the four winds had to be reconstructed with smaller arches and thinner walls and, on it, a new octagon, dome and lantern, all well reinforced with iron chains [22].

Although dateless, the report by Pedro de Sierra is kept together with those we are commenting on and must belong to this moment. Sierra, rather a sculptor than an architect, had recently completed the coronation of the tower of Santa María de Mediavilla Church in Medina de Rioseco (Province of Valladolid) [23]. He said that the dome was deficient because it was built with two leaves and that the inner one had a "movement" in the ring and the outside one had several damages. For that reason, he proposed to demolish the dome and make it slenderer and with good stereotomy; he also proposed to demolish the octagon and to make a more graceful one. Although he argues that he could not put more weight on the tower, he said he would give a solution if the chapter asked him to do the project [24].

Some months later, on March 25th, 1744, Antonio Pontones presented a report that we can consider definitive, as it seems to gather suggestions and conclusions from the previous ones. It begins by presenting the tower and its proportions, arguing that they are adequate (the walls' thickness must be one-fourth the total width of the tower and the width must be one-fourth the total height, an idea mentioned by Fr. Lorenzo de San Nicolás, author of a book on Architecture wide known in Spain in the 17th and 18th Centuries [25]). However, he argued that the walls to the south face of the tower were thicker than the others and that this could have been a source of seats, but also, he continues, this could be the result of making stronger the walls exposed to inclement weather. As the tower was fitted in its height given the proportion, it could not be higher. He declared, contrary to other reports, that he had not seen any problem in the firsts three bodies of the tower, except that inside there was reused old stone - probably extracted from the medieval Collegiate-Church, dismantled from 1688-92 [26]-. As for the octagon body, he agreed that it was too low and also warned that inside there was reused stone too. He pointed out that the dome had to be dismantled, but that the new one would have to be higher and thicker; therefore, heavier. In this he saw a problem, because upon time it could lead to ruin the crowning of the tower, especially considering that these kinds of work should last for a long time. He proposed two solutions: to eliminate the octagon and dome, to construct a new dome according to the Herrerian primitive plan, placing the bells in the body of the four winds, or to rebuild the octagon with thinner walls, enabling to give it higher height, as with the dome [27].

It does not seem that the chapter took any decision at that time, perhaps due to economic problems. However, the Canon in charge of the building warned the chapter on February 19th, 1746 that a decision had to be made, since the supporting frame of the ruined dome was about to break down. The chapter resolved, in view of the reports, that Antonio Pontones "*is to demolish the dome, and make a wooden spire covered in slate as beautiful and graceful as possible*". Pontones carried out the spire as the chapter had commanded, since the expenses of the work are recorded in the chapter's accounts [28]. For the external shape, Pontones seems to have taken as reference the demolished dome, with its rather depressed form and its octagon shape. Seeing the preserved detailed invoices of the woods used, we have thought that its structure would be linked to examples of "*encamonada*" dome (false dome with a wooden frame) as established by Fr. Lorenzo de San Nicolás on his book [29]; In this way we have made our drawings, showing such wooden structure (fig. 2).

The Lisbon Earthquake came on November the 1st, 1755, once the problem of the dome had been corrected and no further work had been done in the other damaged areas of the tower that some reports

had denounced. We keep the testimony of a great witness: The reredos and choir stalls builder from Valladolid, Ventura Pérez, who kept a diary with the most outstanding facts of his city, was precisely in the cathedral at the time of the earthquake, attending to high-mass: "*the whole city was shaken, even the most eminent temples, palaces and towers, as it was the cathedral, which, as a consequence, the tower clock started striking the time*" [30].

The problems of the tower, which, as we have seen, had a long history, were still noticeable, so at the beginning of 1761, the chapter asked Antonio Pontones again to give a report, which has not been found. As one of the greatest Spanish architects, the Royal Architect Ventura Rodríguez, was in the city, the chapter also asked him. He produced a report, which has not appeared either, and an extraordinary plan of the tower, signed in Valladolid on April 12th, 1761, which we have already mentioned, where he explained both his solution to the building problems and the way to execute it; the chapter, convinced by the Royal Architect, decided to carry out his project [31]. It consisted of reinforcing the tower with four large iron chains. The lowest one would be placed around the pedestal of the second body of the tower; the second, under the cornice that finished off this body; the third, under the cornice that ended "the four winds" and the fourth, under the cornice of the octagon. To arrange these chains, instead of a costly climbing structure up the entire tower, he engineered a flying scaffold that would be lowered from the arches of the four winds so that the first two chains could be fixed. The scaffolding platforms could be raised or lowered using a large winch. Once this operation was finished, the winch would be moved to the octagon to place the third chain; finally, the fourth one would be placed with a simple wooden platform. The Master Manuel Godoy was in charge of the implementation, finishing in 1764. It is possible that Pontones visited the works, called by the chapter, perhaps to give his opinion about a problem during the works [32]. For the next two decades, the tower did not appear to give any significant problems.

However, on March 11th, 1788, a stone was detached from the second cornice, just below the clock dial, and in its fall, it also knocked down some pieces of the cornice which finished off the first body. By chapter order, the master builder Francisco Javier de la Rodera visited the tower and issued a report the following day. He declared that the fall had happened due to the roots of the vegetation colonising the tower, retaining humidity. He saw the tower without problems except for several broken stones in a corner by the pedestal of the four winds body, a damage that, according to him, could not be related to the fall of the stone, because it was an older one; he recommended to preserve the cornices from humidity, because he says that dampness is the cause of ruin in uncovered works [33]. The chapter did not seem satisfied and decided that two prestigious architects, Francisco Álvarez Benavides, one of the most outstanding architects of the Valladolid Neoclassical period, together with Juan Urrechaga, had to examine the tower. Both visited it in detail a week alter the stone falling and reported that the tower was safe and that the event was not related to the great floods that Valladolid had suffered a few weeks before. They declared that the breakage had simply been because the lime joining the stones under the walls of the body of the four winds had shrunk more than the centre of the tower walls by virtue of the differential efforts and that is why the piece, carved and placed in the shape of an arch key, had fallen, dragging the loose pieces of the other cornice. Despite this opinion, it seems that the tower showed more and more problems, because in the summer of 1806, the Chapter required a new report on the tower, this time by Fray Cristóbal de Tejada, architect from the Monastery of El Escorial. The tower showed infirmities on one of its southern sides, and apparently the pedestal of the body of the four winds in that sector was broken, as Rodera's report noticed almost twenty years earlier. The monk ruled that the tower was safe, that he had not seen damage in the arches or collapses in the walls and that there was only a small repair to be done in that sector; the outer wall-facing was somewhat uneven (apparently, bulging, as he talks of "*advanced stones*"), for which he recommended using a scaffolding system like that used by Ventura Rodríguez almost half a century earlier. After that, part of the outer wall-facing of the damaged area would be removed and consolidated, to re-assemble it again, holding it with pieces of iron. He left the master architect of the cathedral Ventura González Sanz in charge of the work [34].

It is almost certain that this work was the one referred to by a master builder when the tower collapsed in 1841, he told the military engineers who examined the damage that "*thirty years ago, a thirty-foot-long stone work was fit into the same angle that fell yesterday*" [35].

Finally, in 1820 two reports were presented to sort out the broken beams of the bell chamber floor. They mentioned the problems with rain water that the tower had. [36].

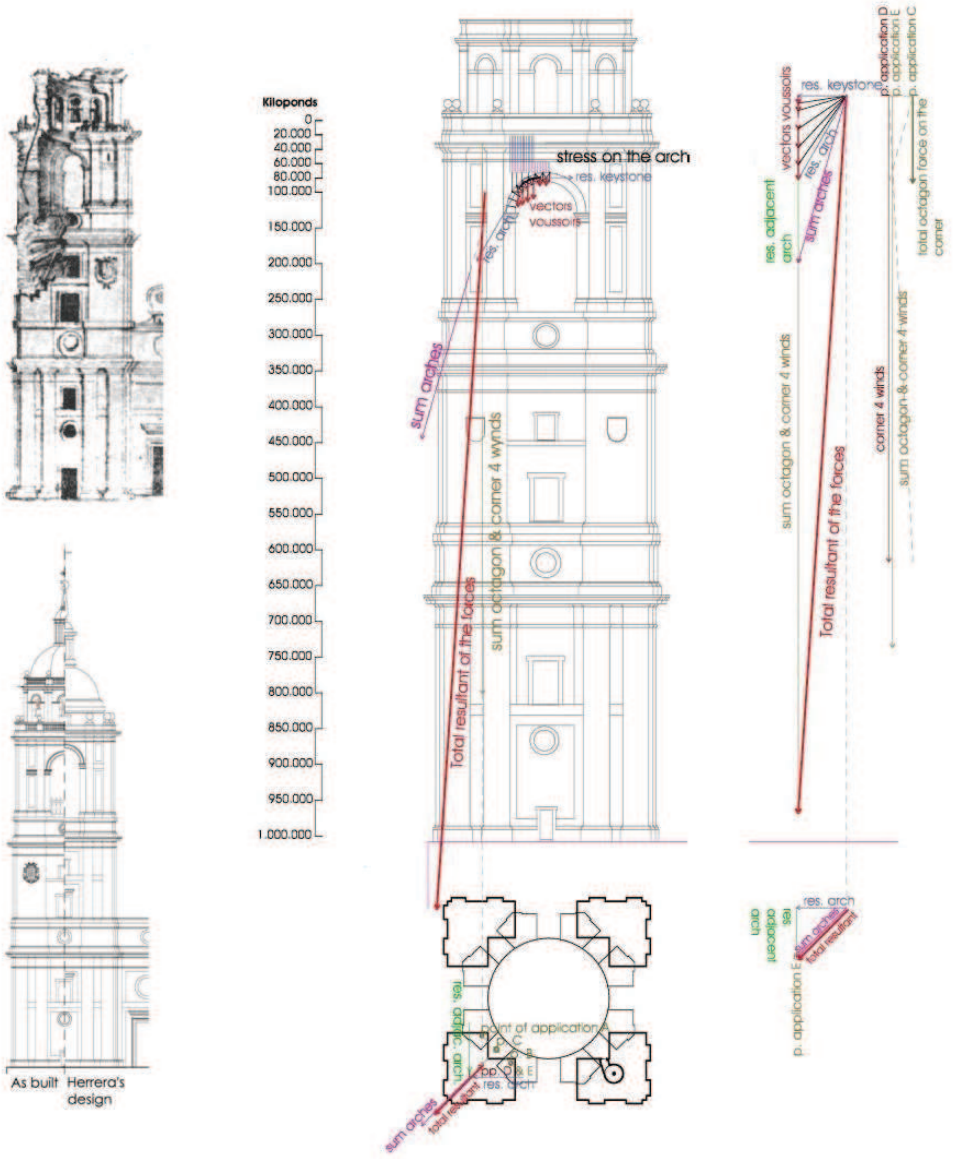


Fig. 3. (a) Top left: The tower just after its 1841 collapse (contemporary drawing by I. Dominguez); (b) Bottom left: comparation between the built tower and its design by Juan de Herrera; (c) Right: Static calculation of the fallen down tower corner. Note the total resultant of the forces (on heavy red) fitted to the angle on the tower's lower section. Drawings by the authors.

5. The collapse of the tower (1841)

On the collapse of Valladolid Cathedral's tower different chronicles have been written. We will follow here what we consider to be the most complete and technical document on this event, the file on the collapse and demolition of the tower conserved in the Municipal Archive of Valladolid.

On the morning of May 31st, 1841, a storm broke over Valladolid, which lasted up to three in the afternoon. Shortly before five o'clock and after a group of bell ringers had come down from the tower, there was a loud noise followed by a louder one: the southwest corner of the tower had collapsed from the second body, dragging the dome, three of the sides of the octagon and all the floors, vaults and wooden stairs. Most of the materials cascaded into the tower itself and out of the cathedral, to the Southwest (fig. 3a). At the time of the plummet, the chief bell ringer and his wife were inside their house in the tower. Quickly, he took refuge in the niche of a window, trying to impulse his wife with him, but he did not succeed and she was dragged by the materials [37]. The ringer was taken to safety and soon it was noticed that his wife had survived too in the low chapel of the tower, buried by the materials. She was finally rescued the morning after.

The City Council, meeting in a permanent session due to the seriousness of the event, requested the four architects of the city a first report. They stated that what was left of the tower was impossible to save, since the walls were very ruined, and they regarded the construction of the tower had been of bad quality, with soft stone wall-cores and the facing of harder stone, without unions between the core and the facings. The tower, according to them, had had problems for more than sixty years (more than eighty since the placement of the chains designed by Ventura Rodríguez). The architects decided to take duty turns to control the evolution of the ruins.

On June 1st, the three military engineers of the base of Valladolid arrived on the scene. In their report they emphasized, like the architects, the bad construction, to which they added "*the worse quality of the mixtures*" of lime used; in the lower body they did not see any damage, so they ruled out foundation problems, although, unlike the architects, they did not find the state of what was left of the tower alarming and they only needed to demolish what was left of the octagon of the third body.

The architects, however, were seeing during their duties the evolution of the construction remains: at seven in the evening of that day, they noticed that one of the pendentives of the body of the four winds was cracking and some wall were collapsing; during the night they noted the falling down of the pendentive and the detachment of two voussoirs from the arches of the third body while the cracks increased; in the morning of June 2nd, new cracks appeared in the third body and the southeast corner of the tower were collapsing; during the first hours of the afternoon they saw that the wall-facing of the southern facade of the tower was splitting.

On the June 5th, the military engineers produced a new report. This time they noticed four ancient fissures, concealed with lime, on the north face of the tower, just below the arches of the third body and close to the angles, so now they thought of a foundation seat, but without major consideration. For them, the collapse of the southeast corner was "*very light*" and the remains of the tower were in no danger of immediate ruin. Ten days later, the architects made another report in which they mentioned the great collapse of the tower walls and sentenced the demolition of everything except the first body and the base of the second. The Chapter was in a terrible economic situation, after the Mendizábal's Confiscations, reason why they requested the City council's help for the demolition; after several eventualities, one prisoner, Francisco González, offered the City council to dismantle the high parts of the tower so that his sentence would be reduced. His offer was accepted; Gonzalez, at the head of a group of inmates, dismantled the tower during the following months, except for its lower body and a small part of the second, practically what is preserved today [38]. The brick vault of the tower lower chapel was rebuilt and the tower remains were covered with a simple roof (fig. 1a).

6. Conclusion: a technical approach to the problems of the tower

Performing a diagnosis of the pathology of a disappeared building from something less than two centuries ago and counting on the reports of the time -with its sometimes biased and contradictory comments- is a difficult commitment task. However, after having exposed the pathological history of our

tower, we are going to try to understand the pathological process, its causes and its connection with the Lisbon Earthquake in 1755.

To start and have a good tool for this mission, we have made a structural static graph calculation of the collapsed corner of the tower (fig. 3c). First, let us examine the 1841's fall with its aid. The documentation provided tells us that the tower fall produced two consecutive noises, the second being greater. In our opinion, this occurred because an external section of the wall collapsed first, in a sector in which, as we have seen, the wall-facing was giving problems for decades (remember that in 1788 it is mentioned as an old damage); in the structural calculation we provide (fig. 3c), it is observed that the resultant of the forces of the tower crossed near the edge of the wall in the two lower bodies; therefore, when an external part of the wall collapsed, the result of the forces had no wall to pass through and as a consequence the entire corner of the tower fell, causing the second, louder noise.

More difficult is to clarify why the wall broke down into leaves and its outside fell. We can dismiss the foundation seat because we conserve the first body of the tower and there we have not observed any damage of such consideration that could support this hypothesis, although the River Esgueva ran next to the tower. On the other hand, it has already been said that both the architects and the military engineers, who judged the construction when the tower collapsed, criticized its poor quality and its lack of unions. The problem could come from the fact that the lime from the wall-core retracted in the years thereafter its construction, leaving the weight of the tower in the two-thin wall-facings (interior and exterior), to make them buckle; we also discard this since the repair of the facing carried out in 1806 by partially disassembling it would have been difficult and could have easily led to the fall of the tower. Therefore, we are inclined to think that the facing would have rather been pushed by one of the leaves into which the wall would have been divided by discontinuities in its bosom. These discontinuities, product of its bad construction, would have been aggravated by the leaks that we know the tower had during practically all its time: when the water drained from the terrace between the third and fourth bodies (something of what J. de la Calle had warned in his report in 1740) it would drag the lime, producing new seats and, upon freezing, it would make bigger discontinuities [39]; reinforces this hypothesis that the broken corner of the tower was the most hit by rainfall, taken into account the prevailing winds in Valladolid.

On the other hand, both 1841 engineers' reports and previous ones mentioned the vertical cracks that the tower had in its corners, just below the body of the four winds, whose corners carried parts of the lower walls, while those under the arches were unloaded; this would cause differential stresses in the walls that would cause such vertical cracks (years ago, one of these was still visible on the corner of the lower body, as show 1930s. photographs). These cracks, together with the internal discontinuities, could have freed the outer part of the corner from the rest of the walls [40], pushed outwards with the different filtrations produced by the rainfall; it is interesting to note that the collapse occurred just after a storm.

Nowadays, these problems would have been solved by means of sewing and limewater injections in the walls of the tower, a technique that naturally did not exist in 18th Century; for that reason, the intervention of Ventura Rodríguez in 1761 reinforcing the tower could had been a system to avoid the disintegration and separation of the walls of the tower; the loss of the report presented by this architect prevents us from knowing the true reasons for his actions. It has already been seen, in the reports of the 1740s, that most of the consulted architects doubted the tower's strength, even before the Lisbon Earthquake: some already spoke of cracks and unanimously claimed the need to remove weight from the construction; indeed, our study of graphical statics yields the result of how tight was the static of the element, with the resultant-force about to leave its walls in the lower part of the tower; this allows us to see that the problems were prior to the earthquake and that this was not the triggering cause, although it may have added to the problem; besides, we have already mentioned that in the region, the intensity of this earthquake was lower than expected given the geographical situation and that the only significant damage in the area seems to have been the tower of the Collegiate-Church of Ampudia (Province of Palencia), that has a graceful crown with pieces presenting little stability.

Finishing on the beginning, we have seen that the bad construction of the dome that topped the tower, together with the action of the rainfall, caused its ruin, thus it had to be replaced by a wooden dome; we think that, in summary, the same can be said about the causes of the ruin of the rest of the tower.

References

[1] Fernández del Hoyo MA. *Inundaciones, incendios y epidemias. Cuadernos vallisoletanos, 7.* Valladolid: Caja de Ahorros Popular; 1986.

[2] Rivera Blanco J. Las restauraciones de la Catedral de Valladolid. In: Fernández Muñoz AL, editor. *Restauración arquitectónica*, Valladolid: Universidad de Valladolid; 1992.

[3] García Chico E. *Documentos para el Estudio del Arte en Castilla*. *Vol. I.* Valladolid: Universidad de Valladolid; 1940.

[4] Cano Sanz P. *Antonio San José Pontones. Arquitecto Jerónimo del siglo XVIII*. Madrid: CSIC; 2005.

[5] Udías Vallina A. *El terremoto de Lisboa en España: (testimonios inéditos).* Brenes: Muñoz Moya; 2010.

[6] Martínez Solares, JM. *Los efectos en España del terremoto de Lisboa: (1 de noviembre de 1755*). Madrid: Dirección General del Instituto Geográfico Nacional; 2001.

[7] Edited in: Bustamante A. *La arquitectura clasicista del foco vallisoletano (1561-1640).* Valladolid: Instituto Simancas; 1983.

[8] Chueca Goitia F. *La Catedral de Valladolid: una página del Siglo de Oro de la arquitectura española.* Madrid: CSIC; 1947.

[9] Martín González JJ. La torre de la Catedral de Valladolid. In: *Boletín de la Real Academia de Bellas Artes de San Fernando* 1995; **81:**91-126.

[10] Canesi M. *Historia de Valladolid (1750)*, *Vol III*. Valladolid: Grupo Pinciano; 1996.

[11] "*Obra Nueva*" books 1667-1710. Valladolid Cathedral's Archive (from now, ACV), boxes 780-781.

[12] Redondo Cantera MJ. La Catedral de Valladolid y su maqueta (1780-1795). In: *Homenaje al Profesor Martín González.* Valladolid: Universidad de Valladolid; 1995.

[13] Receipt for 1216 Reales de Vellón signed on May 6th, 1764 by Agustín de la Fuente, ACV, box 792.

[14] Report by maestro de obras Manuel Serrano (begining of 19th Century). The document has been publised in: Roldán G. La torre de la S.I. catedral de Valladolid y la intervención del arquitecto D. Ventura Rodríguez. In *Informe que hizo el arquitecto de S.M.. Ventura Rodríguez en el año de 1768, de la Santa Iglesia de Valladolid*. Valladolid: Colegio Oficial de Arquitectos; 1987.

[15] A facsimile of the plan was edited in *Informe que hizo el arquitecto de S.M. D. Ventura Rodríguez en el año de 1768, de la Santa Iglesia de Valladolid*. Valladolid: Colegio Oficial de Arquitectos; 1987.

[16] García Chico E. *Documentos para el Estudio del Arte en Castilla*. *Vol. I.* Valladolid: Universidad de Valladolid; 1940.

[17] Report by Antonio Pontones, April 3rd, 1740. ACV, box 790.

[18] Alonso Romero J. *La arquitectura barroca en El Burgo de Osma*. Soria: Centro de Estudios Sorianos; 1986.

[19] Report by Joseph de la Calle. ACV, box 790.

[20] *Libro del Gasto que tiene el reparo de la Media Naranja de la Torre.* 1743. ACV, box 783.

[21] Report by Fr. Francisco de la Visitación. ACV, box 790.

[22] Report by Juan Esteban. ACV, box 790.

[23] Martín González JJ. *Arquitectura barroca vallisoletana*. Valladolid: Diputación Provincial de Valladolid; 1967.

[24] Report by Pedro de Sierra. ACV, box 790.

[25] San Nicolás L. *Arte y uso de Architectura, parte primera.* Madrid: Manuel Román; 1736 (First Edition, 1639).

[26] "*Obra Nueva*" book 1688-1692. ACV, box 781.

[27] Report by Antonio Pontones, March 25th, 1744. ACV, box 790.

[28] *Libro del Gasto que tiene el reparo de la Media Naranja de la Torre.* 1743. ACV, box 783.

[29] San Nicolás L. *Arte y uso de Architectura, parte segunda.* Madrid: Manuel Román; 1736 (First Edition, 1639).

[30] Pérez, V. *Diario de Valladolid*. Valladolid: Grupo Pinciano; 1983.

[31] Roldán G. La torre de la S.I. catedral de Valladolid y la intervención del arquitecto D. Ventura Rodríguez. In *Informe que hizo el arquitecto de S.M.. Ventura Rodríguez en el año de 1768, de la Santa Iglesia de Valladolid*. Valladolid: Colegio Oficial de Arquitectos; 1987.

[32] Documents about this intervention archived in ACV, box 792.

[33] Report by Francisco Javier de la Rodera, March 12th, 1788. ACV, box 792.

[34] Documents published in: Roldán G. La torre de la S.I. Catedral de Valladolid y la intervención del arquitecto D. Ventura Rodríguez. In *Informe que hizo el arquitecto de S.M.. Ventura Rodríguez en el año de 1768, de la Santa Iglesia de Valladolid*. Valladolid: Colegio Oficial de Arquitectos; 1987. These documents are archived in ACV, box 792.

[35] File about the collapse and demolition of the Cathedral Tower. Municipal Archive of Valladolid (AMVA), No. 437-2.

[36] Documents published in: Roldán G. La torre de la S.I. Catedral de Valladolid…

[37] *Papeles sobre la ruina de la torre verificada el día 31 de Mayo de 1841 á las cinco de la tarde*. ACV, box 792.

[38] File about the collapse and demolition of the Cathedral Tower. AMVA, No. 437-2.

[39] Heyman J. *El esqueleto de piedra. Mecánica de la arquitectura de fábrica*. Madrid: Instituto Juan de Herrera; 2005.

[40] Heyman J. *Teoría, historia y restauración de Estructuras de fábrica, Vol, I*. Madrid: Instituto Juan de Herrera; 2015.