

A Vertical Palimpsest. Construction and structural evolution of the Bell Tower of the Mosque-Cathedral of Córdoba

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Fig. 1

Bell Tower of the Mosque-Cathedral of Córdoba. General view from the Patio de los Naranjos (picture by I. Cuerda-del-Valle, 2025).

Abstract

The Bell Tower of the Mosque-Cathedral of Córdoba is one of the most significant composite towers in the western Mediterranean. Rising 54 m above the historic centre, it encloses the caliphal minaret of 'Abd al-Raḥmān III, which now acts as the structural core of the present tower. This article interprets the tower as a vertical palimpsest, in which successive historical layers have reshaped the structure while preserving key traces of its previous forms. Drawing on earlier studies, archival sources, recent 2D/3D reconstructions and an on-site survey, it reconstructs the main construction phases of the tower and analyses their implications for its geometry and structural behaviour. The tower is understood as a composite vertical system, in which the caliphal core, the later Christian masonry shell and modern interventions interact. The study provided a preliminary geometric and structural framework to guide future seismic and geotechnical assessments of this complex heritage structure.

Keywords

Heritage tower, Mosque-Cathedral of Córdoba, Construction phases, Composite masonry.

Introduction¹

The Mosque-Cathedral of Córdoba is a key monument – UNESCO World Heritage Site since 1984 – for understanding the architectural and urban history of al-Andalus and of later Christian Córdoba. Its Bell Tower occupies a special place in this narrative. Since the tenth century, the vertical element located at the north-west corner of the *Patio de los Naranjos* has concentrated the functions of calling to prayer, marking liturgical time and providing a visual landmark for the city. At the same time, it has undergone profound transformations in form, construction and meaning, making it a paradigmatic case of a vertical palimpsest in which Islamic and Christian phases coexist within a single tower (fig. 1).

A fundamental systematic study of the caliphal minaret is the work by Hernández Giménez (1975), who reconstructed its exterior and interior configuration on the basis of archaeological excavations and documentary sources. More recently, Ortiz Cordero (2018) has revisited this material in the framework of virtual reconstructions of the Mosque-Cathedral. The Plan Director of the Mosque-Cathedral (Ruiz Cabrero et.al, 2020), together

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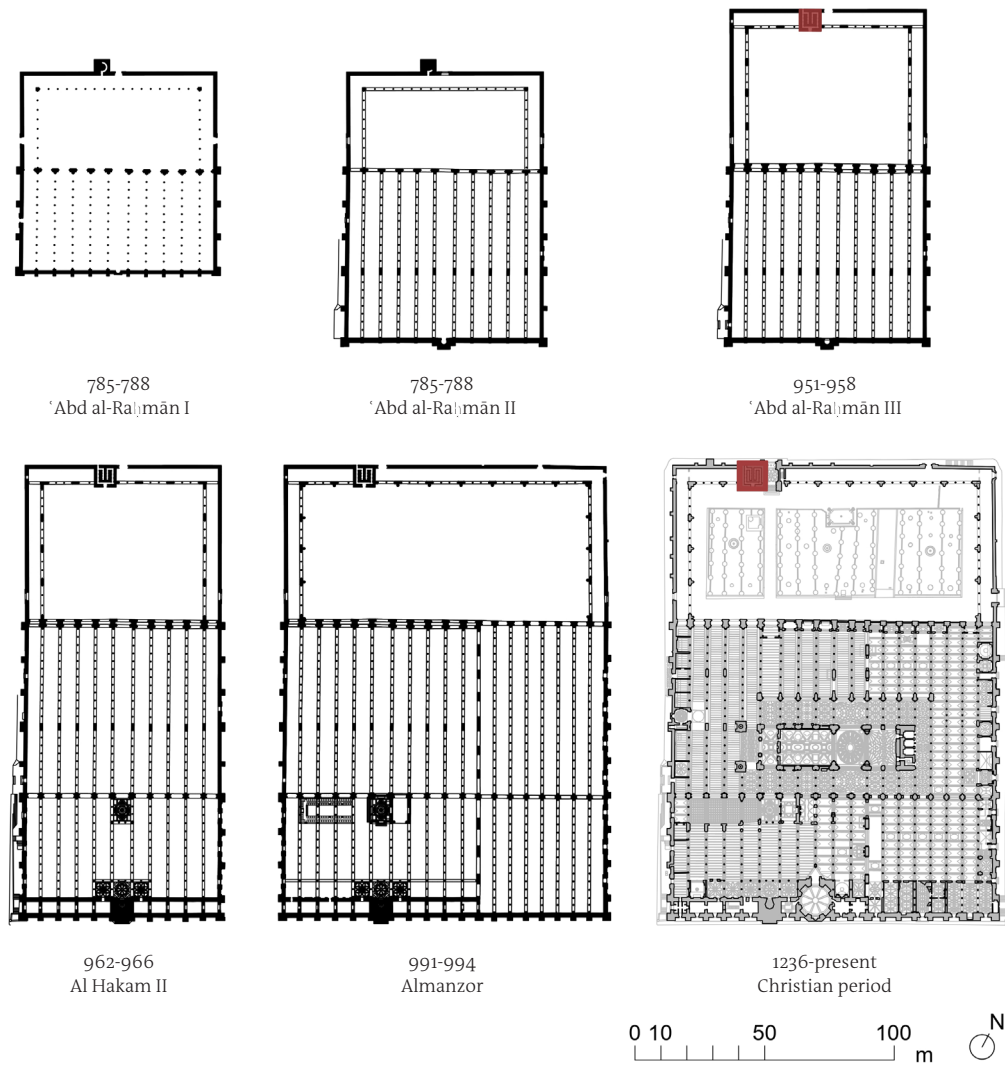


Fig. 2
Chronological timeline of the Mosque-Cathedral of Córdoba, with the Bell Tower highlighted in red (based on Almagro, 2019).

with studies by Almagro Gorbea (2019) provide an updated synthesis of later interventions and of the present conservation strategy.

From a structural and geotechnical perspective, the Tower can be seen as a complex vertical system composed of successive envelopes, floor levels and stair structures, supported on a heterogeneous historic subsoil. The earthquake of 1589, which damaged the reused minaret (Hernández Giménez, 1975), and the Lisbon earthquake of 1755 ($M_w = 8,5$), which reshaped perceptions of seismic hazard across much of the Iberian Peninsula provide two key moments for understanding why the tower has been strengthened, enveloped and maintained rather than replaced. This article therefore proposes a threefold reading: historical, constructive and structural. It focuses on the architectural and geometrical evolution of this vertical element and on its structural interpretation. The aim is to provide a clear description of the construction phases and of the internal configuration that will underpin future geotechnical and seismic analyses of the Bell Tower's behaviour, in line with recent 3D numerical modelling developed for the tower itself (Romero-Sánchez et al., 2025).

Historical and geometrical evolution of the tower

The development of the Bell Tower closely follows the main historical phases of Córdoba and of the Mosque-Cathedral itself. The chronologies of the monument place the construction of the caliphal minaret under ‘Abd al-Raḥmān III between 951 and 958, after the first two enlargements of the mosque (‘Abd al-Raḥmān I and II) and immediately before the major extension of al-Ḥakam II and the later works of Almanzor (Hernández Giménez, 1975) (fig.2). In these decades Córdoba, capital of the Umayyad caliphate of al-Andalus, aspired to rival the great centres of the Islamic world, such as Damascus and Baghdad. The new minaret was one of the most visible architectural expressions of this political programme, both in its scale and in the sophistication of its formal language.

The caliphal minaret has been studied in detail by Félix Hernández Giménez in *El alminar de ‘Abd al-Raḥmān III en la Mezquita Mayor de Córdoba. Génesis y repercusiones* (1975), and his reconstruction was later refined by Almagro (2019) and Ortiz (2018). Based on these studies, the minaret can be described as a square-plan tower divided into two main masonry bodies of different height and a crowning element. The original total height was on the order of 47 m: the lower body measured 30.8 m, while the upper body was about 10.9–11.0 m high and was crowned by a hemispherical bronze dome (4.27 m in diameter) and the *yamur* (5.3 m).

At ground level, the external side of the lower body measures about 8.49 m, a value compatible with the 18 *codos* mentioned in the Arabic written sources when interpreted using the *codo mamuní* derived by Hernández (Hernández Giménez, 1975). The external walls of this body have an average thickness close to 0.97 m (two *codos mamuní*), while the central longitudinal wall that separates the stair compartments measures approximately 0.72 m at the base and tapers to around 0.33 m in the preserved upper courses (Almagro Gorbea, 2019). These dimensions confirm the exceptional scale of the Córdoba minaret, both in footprint and in wall thickness.

The internal organisation corresponds to a single masonry core, whose interior is structured by two central masonry piers that define the two stair compartments, separated by a central longitudinal wall. Each compartment contains a stone stair that rises in the opposite direction to its twin, so that the two flights only meet at the top. The central wall becomes thinner with height while the external walls remain constant (Ortiz Cordero, 2018). The sections and plans produced by Ortiz (2018), show that the two piers and the longitudinal wall together with the external walls, divide the interior into three parallel vertical bays, stitched together by the two opposing stair flights.

The exterior elevations articulate this compact structure with a regular pattern of openings. In the lower body, the north and south façades display pairs of horseshoe-arched windows, while the east and west façades contain triple-arched openings. The second body is open on all four sides and is finished with a parapet of Syrian-type merlons.

A distinctive constructive feature of the minaret is the presence of timber tie belts embedded in the masonry. Ortiz (2018) identifies two timber belts – *encadenados de madera* – located above the two orders of windows of the lower body. They are formed by pine beams with a section of approximately 24 × 23 cm, housed in channels carved slightly larger than the beams themselves. Today only fragments of these beams are preserved, and the surviving pieces have lost a significant proportion of their original cross-section (fig. 3). The empty recesses now appear as roughly square cavities, about 25 × 25 cm, visible from the interior of the tower during the ascent. In geometrical terms, these tie belts define two continuous timber rings at specific levels of the shaft, embedded within the masonry of the walls.



Fig. 3
Timber tie belts embedded in the masonry of the caliphal minaret (picture by I. Cuerda-del-Valle, 2025).

After the Christian conquest of Córdoba in 1236, the minaret was reused as the bell tower of the new cathedral. Documentary and iconographic sources compiled indicate that in this period the essential geometry and structural configuration of the minaret were preserved (Ruiz Cabrero et.al, 2020). All in all, the transformation was functional and symbolic, as the same vertical element continued to organise the time and the call the community together, now in the context of a Christian cathedral.

A decisive turning point came at the end of the sixteenth century. The earthquake of 1589 caused damage to the reused minaret, particularly in its upper part, and led the Cabildo to promote the construction of a new tower that would incorporate and protect the caliphal remains. The solution adopted was not to demolish the Islamic structure but to encapsulate it within a new masonry envelope. In 1593, Hernán Ruiz III began the first constructive phase of the cathedral Bell Tower (Ruiz Cabrero et.al, 2020).

From an architectural and geometrical standpoint, this intervention can be understood as the erection of a second tower around the first one. From a geometrical standpoint, it involved three main modifications. First, the footprint of the tower was enlarged from the approximately 8.5 m side of the minaret to a nearly square plan of about 11.4×11.5 m for the new bell-tower shell, as confirmed by recent survey drawings. Second, the total height was increased to 54 m by raising the upper bodies and redefining the crowning. Third, the façades were regularised according to Renaissance criteria, with pilasters, cornices and a new bell chamber occupying the upper third of the composition (Almagro Gorbea, 2019) (fig. 4). The current Bell Tower preserves the remains of the caliphal minaret as its central core; approximately the lower 22.5 m of the original first body are still in situ (Hernández Giménez, 1975). Between the sixteenth and eighteenth centuries, successive Christian

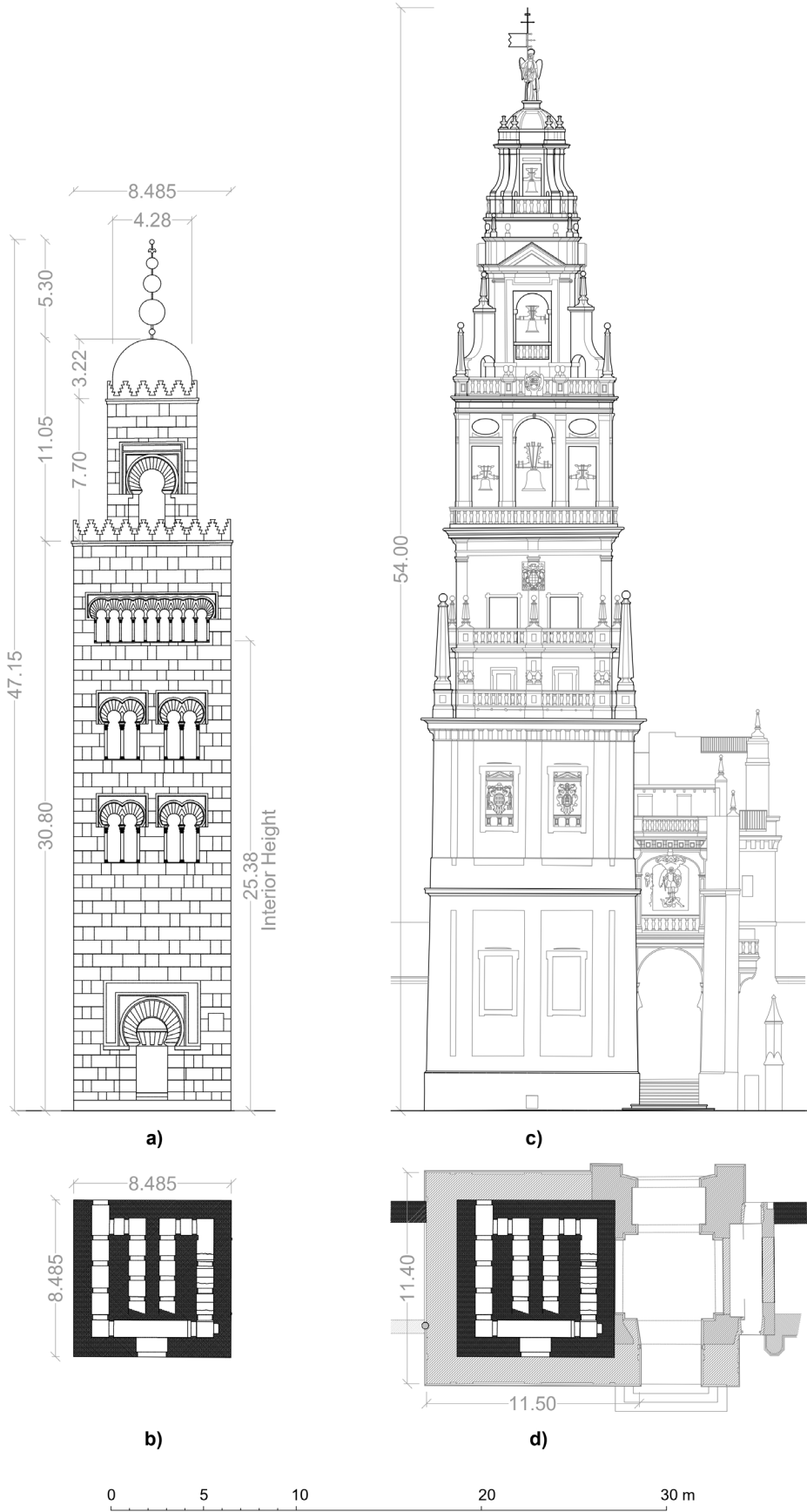


Fig. 4 Ground plans and south elevations of the caliphal minaret and the present Bell Tower: (a) south elevation of the original minaret; (b) ground plan of the original minaret; (c) south elevation of the current Bell Tower; (d) ground plan of the current Bell Tower, showing their geometric relationship (drawing by the author, based on Almagro, 2019).



Fig. 5
Puerta del Perdón (picture by I. Cuerda del Valle, 2025).

Fig. 6
Timber platform around the dome of the Puerta del Perdón, connecting to the original stair of the caliphal minaret (picture by I. Cuerda del Valle, 2025).



Fig. 7
Local strengthening and support elements in the bell chamber of the Christian tower (picture by I. Cuerda del Valle, 2025).

Fig. 8
Internal connectors and infill masonry tying the inner core and outer walls of the original minaret (picture by I. Cuerda del Valle, 2025).

additions and external claddings progressively altered its outward appearance. In 1664 Gaspar de la Peña gave the structure its definitive profile with the installation of the statue of San Rafael that crowns the composition, establishing the silhouette that remains today (Ruiz Cabrero et.al, 2020).

In structural terms, the Islamic shaft thus became the inner core of a composite system, while the new outer tower provided both a renewed urban image and an additional load-bearing shell.

In the wider historical context, the Lisbon earthquake of 1755 had a major impact on architectural practice throughout the Iberian Peninsula and it represents one of the principal milestones in the modern history of the Mosque-Cathedral. However, no specific post-1755 reconstruction campaign has been identified focused exclusively on the Bell Tower of the Mosque-Cathedral of Córdoba.

More recent interventions have concentrated on restoration, conservation and functional adaptation. The long programme of works directed by Ricardo Velázquez Bosco shaped much of the current appearance of the Mosque-Cathedral and included operations on the Bell Tower. Subsequent campaigns, documented in the 2020 *Plan Director*, addressed the masonry of the shaft, the bell frames and the access systems, culminating in a major restoration completed in 1991 (Ruiz Cabrero et al, 2020). The tower was reopened to visitors in 2014 after a prolonged closure, following new safety and access works promoted by the Cabildo.

An on-site survey by the author shows that the current visitor route starts to the east of the *Puerta del Perdón* (fig. 5). From this point, visitors ascend a modern timber stair that rises to the level of the gate's dome, which is now covered by a new timber structure. A timber platform allows a perimeter circulation around the dome and leads to one of the original staircases of the caliphal minaret. This historic masonry stair is followed for approximately one storey, after which it merges with the second original stair, now integrated into a single continuous flight, while the other historic branch is no longer accessible as an independent path. These observations indicate that contemporary patterns of use and safety requirements have introduced an additional layer in the circulation system of the tower, superposed on the earlier structural and spatial configuration.

Read together, the caliphal minaret, the Christian bell tower and this contemporary layer support the interpretation of the whole as a vertical palimpsest: a long-lived building in which each major phase leaves a recognisable geometrical and spatial trace instead of erasing the previous one (fig. 6). This stratified condition provides the basis for the structural interpretation developed in the following section.

Structural interpretation: a composite vertical system

From a structural viewpoint, the present Bell Tower can be interpreted as a composite vertical system formed by three main components: (i) the caliphal shaft, including its perimeter walls, central walls, stair cores and timber ties; (ii) the later Christian masonry shell, with its walls, buttresses, bell chamber and boundary conditions; and (iii) the modern elements associated with access, safety and conservation. These components are not independent; they interact through contact surfaces, fillings and horizontal structures that must be considered explicitly in any structural or geotechnical assessment.

Its approximately 8.5 m square plan, walls close to 1 m thick and central longitudinal wall create a stiff masonry volume with two stair compartments. The stair flights bear on the central wall and on the external walls at each landing, effectively tying them together. From a structural point of view, this configuration represents an efficient typology: the

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Fig. 9

Christian stair flight in the upper part of the Bell Tower (picture by I. Cuerda-del-Valle, 2025).

Fig. 10

Islamic stair with a contemporary reinforcement linking the inner and outer walls of the original minaret (picture by I. Cuerda-del-Valle, 2025).



perimeter walls and internal cores define a continuous vertical load path with limited slenderness, perforated only by regularly spaced openings at the upper levels. The double stair, resting on solid masonry at each landing, behaves as a series of internal diaphragms, while the concentration of larger windows in the upper body keeps the lower shaft comparatively compact.

At two levels, timber *encadenados* add a horizontal component to this internal tying system. However, their exact structural function remains debated. Their current condition – with only fragments preserved and square recesses of about 25×25 cm visible from the interior (Ortiz Cordero, 2018) – implies a local loss of effective section at the levels where they appear. These recesses can therefore be interpreted as local discontinuities and potential weaknesses, since the voids interrupt the continuity of the stone courses. Conversely, the elastic properties of the wood can impart some elasticity to the otherwise rigid stone structure.

The Christian works produce an outer shell whose plan measures roughly 11.4×11.5 m (Almagro Gorbea, 2019). This shell thickens the overall section and introduces new walls, cornices and the bell chamber. The inner and outer towers are locally in direct contact. Consequently, the current cross-section cannot be interpreted as a free-standing inner shaft surrounded by an independent cage, but rather as a composite section in which both shells participate, to different extents, in carrying vertical loads and providing lateral stiffness.

Modern interventions have added further diaphragms and connectors as well as local strengthening elements. New landings, slabs and stair structures now link the inner and outer walls at specific heights (figg. 7-10).

Under gravity loads, the primary vertical load path is likely concentrated in the caliphal core, which preserves the most continuous and compact masonry, especially in the lower 20–25 m of the tower. The external shell shares the transmission of vertical actions; in particular, the gravity loads from the upper bodies built in the Christian period are likely to be transferred predominantly to the perimeter walls, with the added buttresses helping to direct and stabilise these loads. As a consequence, the stiffness distribution along the height is non-uniform: a very stiff composite cross-section in the lower zone, and a sequence of thinner, more perforated masonry bodies towards the top.

For seismic assessment, the Bell Tower should thus be understood not as a monolithic prismatic wall, but as a vertically heterogeneous assemblage of masonry with variable materials, stiffness and mass. In addition, it presents internal discontinuities associated with the degraded timber belts and multiple interfaces between the Islamic core and the Christian shell. Any rigorous numerical or geotechnical analysis of the tower will need to incorporate this composite configuration explicitly.

Conclusions

This paper has discussed the Bell Tower of the Mosque-Cathedral of Córdoba as a vertical palimpsest, in which the caliphal minaret of ‘Abd al-Raḥmān III survives as an internal core within a later Christian bell tower. The reconstruction of the main construction phases clarifies the geometric evolution from an 8.5 m square-plan minaret, about 47 m high, to the present 54 m tower with an enlarged footprint, regularised façades and a stratified internal circulation system.

From a structural standpoint, the Tower has been interpreted as a composite vertical system. The caliphal core – with its thick perimeter walls, central longitudinal wall, double stair and timber *encadenados* – provides a compact and initially efficient load-bearing nucleus. The Christian shell adds a second masonry ‘tube’, with buttresses and the bell

chamber, and can be read as a large-scale structural belt built around the damaged minaret after the 1589 earthquake, confining and reinforcing the original shaft instead of replacing it. Modern interventions introduce new landings, stairs and connectors, so that the present cross-section cannot be treated as a single homogeneous wall.

This configuration leads to a markedly non-uniform distribution of stiffness and mass along the height, with a very stiff composite section in the lower zone and more slender, perforated masonry bodies towards the top. For seismic assessment, the Bell Tower should therefore be understood as a vertically heterogeneous assemblage of masonry with variable materials, stiffness and mass. In addition, it presents internal discontinuities associated with the decayed timber belts and multiple interfaces between the Islamic core and the Christian shell. Any rigorous numerical or geotechnical analysis of the tower will need to incorporate this composite configuration explicitly. This approach is consistent with recent finite-element studies carried out on the Mosque-Cathedral (Requena-Garcia-Cruz *et al.*, 2023).

This composite reading is also essential when considering the interaction with the subsoil. The original minaret was founded on the northern edge of the original mosque, and the later Christian shell slightly enlarged the footprint and modified the distribution of loads on the foundations. Although a detailed analysis of soil-structure interaction lies beyond the scope of this paper, identifying these changes is a prerequisite for any rigorous geotechnical and dynamic study of the Bell Tower. Ultimately, understanding the tower as a composite vertical system interacting with a complex subsoil is essential for designing seismic and geotechnical assessment strategies genuinely oriented towards the conservation of slender heritage towers and for safeguarding the material legacy of the multiple cultures that converge in monuments such as the Mosque-Cathedral of Córdoba.

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