Eduardo Torroja, Concrete and Spain's Indigenous Structural Types

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Abstract

In the first half of the twentieth century, the historicist agenda of Spain's moneyed bourgeoisie created a stifling environment characterized by distrust of, and even hostility towards, creativity, innovation and progressive ideas. Nonetheless, despite this historicism, Spain's material poverty and its obsolete infrastructure, engineer Eduardo Torroja's (1899-1961), experimentation in thin-shell concrete structures produced some of Europe's most technically and aesthetically progressive projects, such as the Market Hall in Algeciras, the Zarzuela Hippodrome and the Frontón Recoletos. Torroja's achievements in thin-shell concrete construction were acclaimed internationally by his peers, including Wright, Neutra, Nervi, Polivka, Otto and Salvadori, yet ironically his avant-garde work was also accepted by Spaniards largely because it was inspired in indigenous structural forms, particularly the Catalonian vault. His fusion of this local structural type and the constructive processes of concrete propelled not only Spain's midcentury modernization, but also that of Latin America and other parts of the globe, thanks to its promotion by the Instituto de Construcción y del Cemento, the journal Informes de la Construcción *and the International Association for Shell and Spatial Structures, all of which were founded by Torroja.*

This paper will argue that, between the mid-1920s and his death in 1961, Torroja used his technological advancements in concrete and his adaptation of indigenous forms such as the Catalonian vault as convincing evidence that modern material science, aesthetic theory and innovative form-finding were indeed compatible with traditional structural types. It will consult original, never-published documents extracted from his professional archives in Madrid, including project briefs, cost estimates, conceptual sketches and calculation sheets, and it will cross-reference these documents with theoretical texts such as his 1958 treatise Philosophy of Structures*.*

Introduction

In 1961, Spanish architectural historian Carlos Flores noted that the work of structural engineer Eduardo Torroja represents Spain's first true exploration of the plastic and technical possibilities of cast-in-place reinforced concrete, and that Torroja's innovations with this material established him as one of the world's most renowned structural engineers.[1] Similarly, José Fernández Ordóñez pointed out that, in concrete, Torroja discovered a material whose monolithic qualities for the first time in history allowed an unlimited range of forms, including thin-shell structures that can simultaneously serve as support, enclosure and skin, with extreme material efficiency.[2] Eventually, Torroja's experimentation with concrete shells led to the development of unprecedented structural forms.[3]

By the mid-1920s, concrete had already been used in countless buildings around the world, including several in Spain, among which Flores included Mario Carimiña's Children's Sanatorium (1910-1914, Górliz, Basque Country) and Teodoro Anasagasti's Monumental Cinema (1923, Madrid). However, Flores noted that the antiquated historicism that dominated Spain in the 1910s and 1920s prevented these architects from exploring the plastic and technical possibilities of concrete.[4]

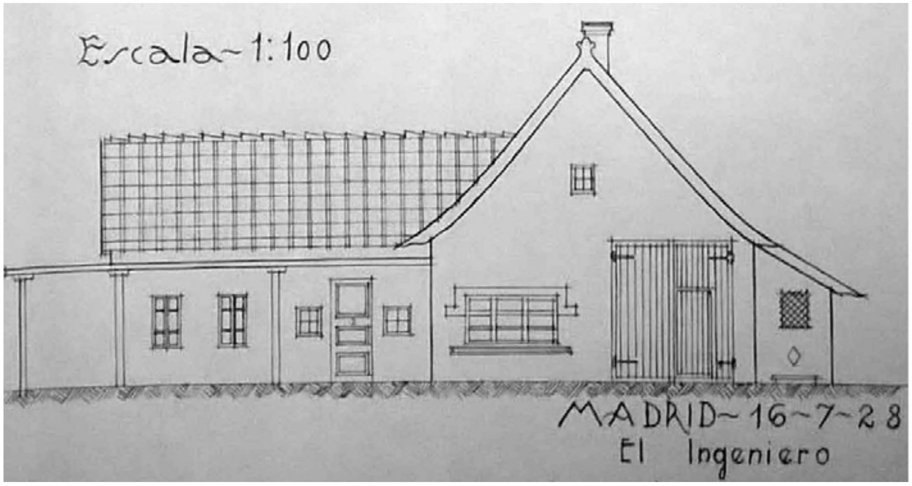
When Torroja graduated from Madrid's School of Engineering in 1923, he took employment with the Compañía de Construcciones Hidráulicas y Civiles (Hidrocivil), one of the largest engineering and construction firms then operating in Spain. In his four-year employment with Hidrocivil, he collaborated with the company's founding engineer, José Eugenio Ribera (1864-1936) on the design for the Sancti Petri bridge in San Fernando (Cádiz, 1926), one of the first bridges to be constructed in Spain with an all-steel superstructure.[5] Torroja's contribution to this project was the design of the reinforced concrete caissons, whose geometry was Torroja's solution to the loads of the bridge and the properties of fluid dynamics.[6] To resist the hydraulic pressure, Torroja devised a double-layer thin-wall system constructed of simple hollow bricks with a thickness of 6.9 centimeters.[7] The outer layer took the form of a hyperbola of revolution, and the inner layer an inverted cone. The void between them was filled with concrete. The complex curving geometry of the caissons at the Sancti Petri bridge foreshadows the forms that eventually dominated Torroja's later works.

Searching for modern forms in Spain's vernacular architecture

In 1927, at age twenty-eight, Torroja left Hidrocivil to found his own studio, Eduardo Torroja, Oficina Técnica, in Madrid. Admittedly, the earliest projects he designed for clients in various locations around Spain reveal none of the innovative structural form-finding of the Sancti Petri Bridge, yet these early independent projects merit mention because they reveal Torroja's interest in Spain's vernacular forms, which would persist throughout his career. That Torroja, a world-renowned structural engineer, would be fascinated with vernacular forms was no surprise to fellow structural engineer Mario Salvadori (1907-1997), who noted that 'Eduardo Torroja is, of course, much more than a great teacher of structures. He is a humanist, a wise administrator of large enterprises, a great engineer, and a zealous researcher,' and that Torroja followed other great humanists who, 'devote their beginning years to a long and thorough study of the fundamentals of their culture.'[8]

Between July 1928 and February 1930 Torroja designed a series of residential projects, most of which were single-family homes for bourgeois clients and small rental vacation houses, which he called *hoteles*. The earliest of these projects, dated between July 1928 and April 1930, was a series of four single-family *hoteles* for a rural site located at the intersection of the La Coruña and Majadahonda highways in El Plantío, at the time an unincorporated tract of agricultural land in the outskirts northwest of Madrid.[9] These *hoteles* exchange the hyperbolic and conical forms Torroja had devised for the caissons of the Sancti Petri Bridge for the traditional forms of the Castilian and Andalusian vernacular.

The first of these *hoteles* (dated July 1928) was a single-story house with a traditional pitched gable roof clad in typical Spanish clay tile; white stucco walls; rough-hewn timber for lintels, sills and jambs; a wrap-around wood pergola; a garage, whose oversized door resembles those of typical Castilian granaries; and a niche for religious statuary.[10] Clearly, this *hotel* was designed to appeal to the sensibilities of the traditional-minded Spanish bourgeoisie. With a smaller footprint, the second *hotel* for El Plantío (dated October 1928), uses similar vernacular details, but exchanges the steeply-pitched gable for a flat roof, parapet and simple cornice.[11] The third *hotel* (dated 10 November 1928), a two-story square with an adjoining garage and WC, also uses a flat roof, parapet and simple cornice.[12] Its façade composition is more minimalist and symmetrical than that of the earlier two, yet it still makes various stylistic references to the Castilian vernacular. Finally, the fourth *hotel* (dated 15 November 1928) is similarly minimalist and symmetrical, yet unlike the other three it replaces the parapet and cornice with a simple rounded corner and it includes a 50 centimeter-high *zócalo* (a non-structural thickening of the wall at its base), which Torroja had extracted from local sources.[13] All four of Torroja's *hoteles* are set back from the property line and surrounded by a garden.[14]



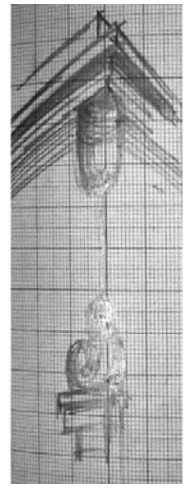


Figure 1. Façade, First 'Hotel' in El Plantío, author: E. Torroja, dated 16 July 1928 (Archivo Torroja, CEHOPU-CEDEX, ETM-014/Caja 004/03 (03 al 06)). **Figure 2.** Sketch, Cornice and Volute Detail, author E. Torroja, undated (Archivo Torroja, CEHOPU-CEDEX, ETM-050/Caja 011/05_04)

While Torroja frequently collaborated with architects such as Augstín Aguirre, Secundino Zuazo, Carlos Arniches and Manuel Sánchez Arcas, to whom he typically deferred in questions of aesthetics and façade composition, the archival evidence for the project in El Plantío makes no mention of collaboration with an architect;[15] therefore, it appears that the façade composition, and the overt references to Castilian and Andalusian sources, were determined exclusively by Torroja, presumably in order to appeal to a bourgeois sensibility. Moreover, his archives also include a number of sketches drawn in his own hand of Andalusian and Castilian vernacular elements such as cornices, corbels and coats of arms.[16] Clearly, these *hoteles* are stylistic copies typical of the period, yet their uniqueness lies in the fact that they were designed by a young structural engineer whose education at the School of Engineering would not have included lessons in composition theory or studies of Spain's vernacular architecture, and who only a few years before had experimented with modern form-finding processes.

Even more importantly, Torroja's structural drawings, cost estimates and calculation sheets reveal that these *hoteles* did not use brick, wood, stone or adobe, which were typically used as structural materials in Spain's vernacular architecture;[17] instead he designed a structural frame consisting of a combination of columns and load-bearing walls, which were to be constructed exclusively in reinforced concrete. Despite the fact that concrete had been used for residential architecture in France and other parts of Europe even before the turn of the century, prior to 1928 it had not been used widely in Spain for single-family residences;[18] in fact, Flores has noted that during the first decades of the twentieth century, buildings that used concrete as a structural material were often ridiculed by Spaniards in academia, in practice and in popular culture.[19]

Although it appears that these *hoteles* were never built, Torroja went to the trouble of detailing columns (L-shaped, T-shaped and cruciform), beams, load-bearing walls and interior partitions, all to be constructed of concrete, and of calculating quantities and estimating material costs of cement, sand, aggregate and reinforcing steel.[20] His innovations with concrete in these *hoteles* even included the use of sawdust as an additive, in a primitive attempt at air-entrainment, presumably intended to reduce cost, as well as the self-weight of the concrete.[21]

The Hotel for the Conde de Mejorada in Seville (dated 29 December 1928, never built), also employs concrete for its structural frame, yet it is even more faithful to the local vernacular than the *hoteles* in El Plantío. With arcades, planters, wrought iron balconies and crenellated parapets, Torroja noted the façade of this building, which was designed as a vacation home for the Count, for its 'extremely sober ornamentation', and that its 'ornamentation has been totally eliminated in order to achieve a type of construction that is truly economic, and inspired in the simple and graceful style that is native to Andalusia'.[22] Moreover, Torroja described the composition of the façade as a rational result of the programmatic organization of the interior spaces, which he linked directly with the logic of the reinforced concrete structural system.[23] Again, the archival documentation includes no mention of a collaborating architect, for which reason the composition of the facades, the selection of concrete as the structural material and the description of the design rationale are most likely Torroja's. A number of other projects Torroja designed in the late 1920s and early 1930s reflect a similar attempt to infuse vernacular forms with the logic and constructive process of advanced concrete structural systems.[24]

From Catalonian vault to concrete shell

In June of 1979, an exhibit entitled 'Modernity in the Works of Eduardo Torroja', organized by the Colegio de Ingenieros de Caminos (Madrid) established a link between Torroja's work and one of Spain's most unique and iconic structural types, the Catalonian vault (*bóveda catalana*). This exhibit positioned Torroja as a member of an elite group of designers including Rafael Guastavino (1842-1908), Antoni Gaudí (1852-1926) and Joan

Rubió i Bellver (1870-1952), whose work demonstrated a clear attempt to resurrect this traditional structural type in contemporary architecture.[25] Their fusion of nineteenth-century technologies, such as mixing slaked lime mortar and Portland cement, with Catalonia's age-old ceramic industry birthed a new breed of pseudo-elastic structures that were unprecedented in both their thinness and their capacity.[26]

Following in the footsteps of Guastavino, Gaudí and Rubio i Bellver, In his search for inspiration in Spain's vernacular architecture Torroja stated that

> It is not out of place to mention the Catalonian vault, as indigenous to the country where it was [*sic*] originated as are olive trees and groves. It is so marvelous in its realization, that theory is taxed to explain and to evaluate its resistant phenomenon, which was so easily and subconsciously sensed by builders long since buried many centuries ago in the same earth from which they made these remarkable bricks.[27]

He was fascinated by the Catalonian vault's ability to span relatively long distances between beams, and to provide a substructure for floors above. The Catalonian vault, also known as the *bóveda tabicada,* or built-up brick vault, is composed of thin bricks laid in multiple layers that are laminated together with gypsum mortar; to span in both the x- and y- axes, these vaults are often repeated as continuous parallel barrel vaults, or laid out in a grid of intersecting groin vaults. In more complex manifestations, the traditional Catalonian vault takes on hyperboloid and/or catenary shapes. The void between the vault and the finished floor above is then filled with earth and rubble.[28] Torroja recognized the inevitable increase in dead load produced by using structural masonry and rubble fill, yet he pointed out that this mass helps in reducing acoustic transfer from floor to floor, whereas 'contemporary very-light floorings often seem too much like drumheads'.[29] He also described this structural type as uniquely appropriate for harsh arid climates such as those of Andalusia and Extremadura, where clay is the dominant soil type.[30]

Given Torroja's early experimentation on hyperbolic geometries in the caissons of the Sancti Petri Bridge, his innovative application of reinforced concrete in the otherwise traditionalist *hoteles,* and his lifelong appreciation for the Catalonian vault, it is no surprise that, by the early 1930s he would begin to experiment extensively with form-resistant thin-shell structures in reinforced concrete. He noted that, when constructed in reinforced concrete, the cylindrical or hyperboloid shell has fewer structural deficiencies than the typical masonry barrel vault because of the increase in shear resistance that results from concrete's monolithic quality, the use of reinforcing steel and the possibilities of stiffening along its edges.[31] The earliest such translation can be observed in the central dome of the Market Hall (Algeciras, 1933 on which he collaborated with architect Manuel Sánchez Arcas).[32] To comply with the program, which required a large, flexible continuous space, Torroja applied his knowledge of intersecting Catalonian vaults. This dome, itself a thin-shell concrete structure with a diameter of 47.8 meters and a thickness of only 9 centimeters at its thinnest point, is intersected by eight short cylindrical shells that radiate outward from the center, which serve to stiffen the shell at its edges, and to concentrate the stresses over the eight support columns.[33] It was the first dome of its kind to be constructed in Spain.[34] The outward thrust of the dome is counteracted by a steel hoop embedded in the beam that connects the eight supports.[35] For this interpretation of the Catalonian vault, Torroja claimed that 'the most suitable material for such domes is obviously reinforced concrete, although there are certain limitations of span as compared with dome shells supported along the whole periphery.'[36] Later, he described his choice of reinforced concrete as uniquely appropriate for such thin-shell structures, given that it allows the shell to be thickened near the points of support.[37]

Figure 3. Exterior, Market Hall in Algeciras, photo dated 1933 (Archivo Torroja, CEHOPU-CEDEX, ETM-093-02_01). **Figure 4.** Interior, Market Hall in Algeciras, photo dated 1933 (Archivo Torroja, CEHOPU-CEDEX, ETM-093-06_01)

That same year (1933), Torroja again applied his study of the Catalonian vault to the design for a retaining wall on the campus of the Polytechnic University of Madrid. On its exposed side, the Cantarranas Retaining Wall, which today supports Madrid's A-6 freeway, is deceptively flat and uninteresting; however, the earthen side is bifurcated at mid-height by a series of buttresses connected by shallow thin-shell concrete vaults, on which the weight of the earth bears, thus resisting the wall's rotational moment.[38] For this project, Torroja chose concrete in order to maximize efficiency and economy.[39]

In 1935 Torroja designed three thin-shell roof structures stiffened by the intersection of multiple vaults, yet instead of intersecting these vaults perpendicularly, as he had done in the Market Hall, the vaults of the Villaverde Church, the Fronton Recoletos and the Zarzuela Hippodrome (all built for sites in Madrid) run parallel to each other, creating a unique seagull-shaped cross-section. At Villaverde he chose to use a large central elliptical vault, which is stiffened thanks to its intersection with two smaller, flanking vaults, also of elliptical cross-section.[40] Like typical Catalonian vaulting, the five-centimeter thick Villaverde vault then rests on a continuous load-bearing wall.[41]

Figure 5. Interior, Frontón Recoletos, photo: Castellanos, dated 1935 (Archivo Torroja, CEHOPU-CEDEX, available at http://www.cehopu.cedex.es/img/bibliotecaD/Cubierta_laminar_fronton_recoletos).

For the roof of the Frontón Recoletos, which was designed in collaboration with architect Secundino Zuazo, Torroja initially experimented with steel, first in transverse trussed girders, then in longitudinal girders. However, he quickly determined that the structural, functional and aesthetic results of these two solutions 'proved to be an unsatisfactory arrangement',[42] and that the vault was superior because it would eliminate all internal structural elements that might obstruct views from the stands, or the smooth ricochet of the *pelota*.[43] He must have had the Catalonian vault in mind when he stated that 'the hand of the imagination instinctively drew out two arcs, the asymmetry of which rhymes with the asymmetry of the hall itself'.[44] In 1957 he described his selection of reinforced concrete as well-suited to the double cylindrical thin-shell roof.[45] Therefore, in the case of the Fronton Recoletos, his selection of reinforced concrete was made to suit the desired form, not vice versa. The thickness of the thin-shell vault varies between 7.8 and 15.8 centimeters.[46] To provide an abundance of north light to illuminate the playing court, and a lesser amount of north light to illuminate the upper stands, he designed two unequally-sized vaults; in both cases he perforated the vault with a triangular grid of skylights.[47]

The program of the Zarzuela Hippodrome, which he designed in collaboration with architects Carlos Arniches and Martín Dominguez, required grandstands with unobstructed views of the racecourse; a betting hall linked directly with the paddock and the stairs to the grandstands, which could be observed from above by a staff mezzanine; and a continuous upper promenade for spectators, with views of the racecourse on one side and the paddock on the other. While their first solution represents a sophisticated and compact vertical layering of programmatic elements, and an initial attempt at a cantilevered roof tapered to accommodate the bending stresses, it also included a rather cumbersome system of counterweights, tiebacks, tie rods and a row of support columns that impeded the spatial and visual connection between the betting hall and the paddock.[48] Torroja himself described this initial solution as 'not very satisfactory'.[49]

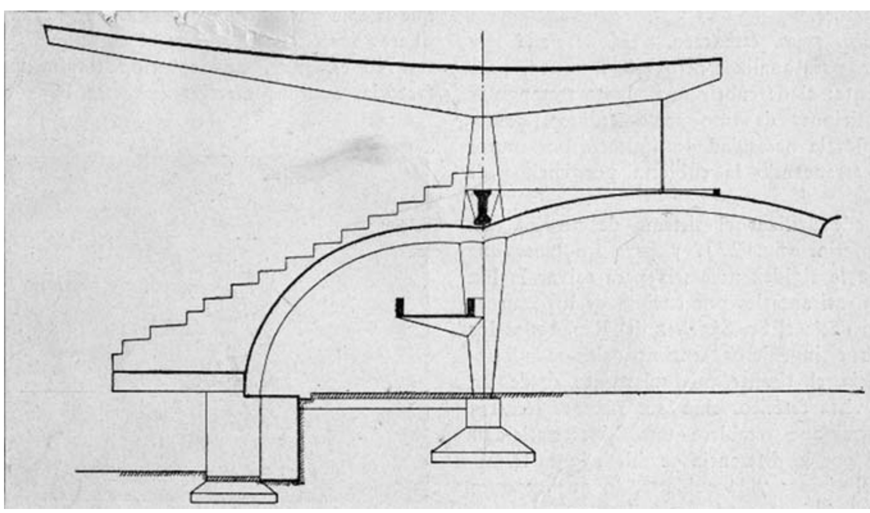


Figure 6. Transversal section (final version), Zarzuela Hippodrome, undated, drawing: E. Torroja (Archivo Torroja, CEHOPU-CEDEX, ETM-115-05_01)

In the first revision they slipped the staff mezzanine and half of the betting hall underneath the grandstands, and eliminated the columns between the betting hall and the paddock by offsetting the weight of the betting hall roof with a more substantial tie member. As a result, the cantilevered roof of the betting hall balances the 13-meter cantilever that covers the grandstands, and the elimination of the columns increases the spatial connection between the betting hall and the paddock.[50] This revision also introduced a smaller cantilever to support the staff mezzanine, in order to reduce the obstructions in the spatial flow of the betting hall.[51]

Figure 7. Grandstand, Zarzuela Hippodrome, photo: B. Tippey

The first and second revisions also reflect an initial attempt to introduce curvature to the cross-section, but only as a series of straight segments. It was not until the third iteration that Torroja returned to the forms of the Catalonian vault; in an attempt to 'refine the ideas further into a clear, well integrated whole', the final revision relied on 'a certain curvature of outline' to the cross-section, which 'seemed so straight-forward and suitable to the purpose that the imagination resisted any new attempt at further development'.[52] He noted that, as a form-resistant structure, the repeating shell eliminates any need of beams, framework or bracing, thereby providing unobstructed views of the racecourse and the paddock.[53] Torroja acknowledged that the ideas behind the structure for the Hippodrome reflect a certain central European influence, particularly that of Ulrich Finsterwalder, Eugène Freyssinet and Franz Dischinger;[54] however, much like the Catalonian vault, the intersection of parallel vaults stiffens the cantilever in the transversal direction, while the curvature permits the shells to act as a deeper beam; this move also allowed him to reduce the thickness of the shells, which ranges from five to fourteen centimeters.[55]

Following the Spanish Civil War (1936-1939), Torroja continued to experiment with concrete and the Catalonian vault. The roof he designed in 1950 (never built) to cover the waiting platform at the Ourense train station hybridized his innovations at the Zarzuela Hippodrome with those of the Fronton Recoletos; in the transversal direction he composed it as a pair of intersecting seagull vaults, similar to Recoletos, and to stiffen it in the longitudinal direction he subdivided these vaults into a series of repeating hyperboloid shells.[56]

In 1955, Torroja collaborated with Venezuelan architect Fruto Vivas (b. 1928) on the design of the form-resistant thin-shell concrete roof of the Club Táchira in Caracas (1956-1957).[57] Torroja modified Vivas' initial concept for the double-curvature roof structure, which stretches over the open-air club spaces, in order to simplify its construction and maximize its structural efficiency, yet without compromising the dramatic organic form.[58] The ten-centimeter thick curving shell structure, which vaults over a massive plinth, allowed for grand arched openings at the Club's perimeter in order to provide unobstructed views of the surrounding valley.[59] Torroja augmented his mathematical analysis of the shell's structural properties by fabricating a 1:10 scale model of the roof and loading it proportionally.[60]

Figure 8. Roof Model, Club Táchira, on display at the Museo Eduardo Torroja, Madrid, photo: B. Tippey

Conclusion

While the work of Eduardo Torroja clearly demonstrates innovative and scientific use of materials, as well as structural form-finding techniques that are representative of modern engineering, his work is also a direct result of his research of Spain's indigenous forms. Even though they were essentially historicist, his earliest independent projects from the late 1920s and early 1930s merged vernacular elements, which he had extracted from rural Castilian and Andalusian sources, with the logic and constructive processes of a reinforced concrete structural frame. Then, his more mature works expanded on the engineering achievements made by Guastavino, Rubió i Bellver and Gaudí. Like these predecessors, Torroja applied his study of the essential properties of the traditional Catalonian vault to the design of thin-shell structures, yet his fusion of these properties with the plastic and technical possibilities of reinforced concrete constitutes a unique contribution to Spain's architecture and structural engineering.

Abroad, Torroja's experimentation with the technical and sculptural potential of reinforced concrete, as well as his exploitation of Spain's vernacular structural types, garnered acclaim from the world's leading architects and engineers. In 1949, Frank Lloyd Wright stated that Torroja "has expressed the principles of organic construction better than any engineer I know";[61] Joseph Siry has pointed out that during the initial design phases of the Guggenheim Museum in New York, Wright considered Torroja as a potential collaborator.[62] While Wright's collaboration with Torroja never actually came to fruition, Richard Neutra's did. Neutra and his partner Robert Alexander retained Torroja as a consultant on the never-built Trebol la Hayada project (1957, Caracas);[63] furthermore, Neutra accepted Torroja's invitation to lecture multiple times in Madrid, and he promoted Torroja's works to architects practicing in the United States, primarily because of Torroja's unique fusion of technical prowess and aesthetic theory.[64] Although they never met personally, in the late 1950s Frei Otto maintained epistolary correspondence with Torroja, and Otto read *Logik der Form,* the German-language translation of *Philosophy of Structures*.[65] For young Spanish architects such as Francisco Cabrero and Miguel Fisac, who graduated from Madrid's School of Architecture during the difficult early years of the Franco regime, Torroja was one of the few Spaniards that promoted modern ideas. Similar to Torroja's work, Cabrero adapted the traditional Catalan vault for the Feria del Campo (1948, Madrid). Fisac exploited both the organic forms of animal bones and the plastic potential of precast/pre-stressed concrete in his development of 'bone-beams', which he used extensively in buildings such as the Center for Hydrographic Studies (Madrid, 1961) and the Alonso Tejada residence (Madrid, 1961).[66]

Endnotes

[1] Carlos Flores, *Arquitectura Española Contemporánea*, (2nd edition, Madrid: Aguilar, 1988), pp. 122-128, 131. The first edition of this book was published in 1961. For their help in the preparation of this article, I would like to thank Dr. Elwin Robison for his assistance in interpreting Torroja's technical terminology, and my research assistant Jenny Glowe, who systematically cataloged the documents I extracted from the Torroja Archive.
[2] José Fernández Ordoñez (ed.), *La Modernidad en la Obra de Eduardo Torroja: Catálogo de la Exposición Celebrada en el Colegio de Ingenieros de Caminos, Canales y Puertos*, (Madrid: Ediciones Turner, 1979), p. 10.
[3] Lilia Maure, *Secundino Zuazo Eduardo Torroja: Frontón Recoletos, Madrid, 1935*, (Madrid: Editorial Rueda, S.L., 2004), p. 23.
[4] Flores, *Arquitectura Española Contemporánea*, pp. 120-122.
[5] Archivo Torroja, CEHOPU-CEDEX, 'ETM-018. Puente de Sancti Petri. Arsenal de la Carraca. San Fernando (Cádiz)', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/obras/ETM-018.htm.

[6] Archivo Torroja, CEHOPU-CEDEX, 'ETM-018. Puente de Sancti Petri. Arsenal de la Carraca. San Fernando (Cádiz)', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/obras/ETM-018.htm.
[7] Eduardo Torroja Miret, *The Structures of Eduardo Torroja: An Autobiography of Engineering Accomplishment* (New York: F. W. Dodge Corp., 1958), p. 85.
[8] Torroja Miret, *The Structures of Eduardo Torroja,* p. v.
[9] This paper consults original copies of the following documents regarding Torroja's design for the *hoteles* in El Plantío, which are kept in the Fondo de Eduardo Torroja Miret, Archivo Torroja, CEHOPU-CEDEX (Madrid). 'Primer hotel de El Plantío: Planos', ETM-014/Caja 004/03 (03 al 06); 'Estudio económico de los hoteles de El Plantío', ETM-014-caja 004-03_02; 'Primer hotel de El Plantío-Cubicaciones', ETM-014/Caja 004/03_01; '2-Hotel de El Plantío', ETM-019/Caja 005/03; '3-Hotel de El Plantío', ETM-020/Caja 005/04; 'Hotel de El Plantío-Cubicaciones/Fachadas', ETM-022/Caja 005/06_01. Hereafter, all references to original documents extracted from Torroja's technical archive will cite 'Archivo Torroja, CEHOPU-CEDEX', the title of the document (in quotes), followed by the call number established by the archive (i.e. ETM-XXX/Caja XXX/XX_XX). The archive's catalog may be accessed at http//www.cehopu.cedex.es/etm/etm_index.htm (last accessed on 13 February 2018).
[10] Archivo Torroja, CEHOPU-CEDEX, 'Primer hotel de El Plantío: Planos', ETM-014/Caja 004/03 (03 al 06).
[11] Archivo Torroja, CEHOPU-CEDEX, '2-Hotel de El Plantío', ETM-019/Caja 005/03.
[12] Archivo Torroja, CEHOPU-CEDEX, '3-Hotel de El Plantío', ETM-020/Caja 005/04.
[13] Archivo Torroja, CEHOPU-CEDEX, 'Hotel de El Plantío Cubicaciones/ Fachadas', ETM-022/Caja 005/06_01.
[14] Archivo Torroja, CEHOPU-CEDEX, 'Primer Hotel de El Plantío – Planos', ETM-014/Caja 004/03 (03 al 06).
[15] Torroja's frequent collaborations with architects is documented in Fernández Ordoñez (ed.), *La Modernidad en la Obra de Eduardo Torroja*, p. 13, 80.
[16] Archivo Torroja, CEHOPU-CEDEX, untitled document, ETM-050/Caja 011/05_04.
[17] Calculation sheets and cost estimates: Archivo Torroja, CEHOPU-CEDEX, 'Estudio Económico de los Hoteles de El Plantío', ETM-014-caja 004-03_02; 'Primer Hotel de El Plantío – Cubicaciones', ETM-014/Caja 004/03_01; '2 - Hotel de El Plantío', ETM-019/Caja 005/03; '3 - Hotel de El Plantío', ETM-020/Caja 005/04; 'Hotel de El Plantío Cubicaciones/ Fachadas', ETM-022/Caja 005/06_01.
[18] Dora Wiebenson, *Tony Garnier: The Cité Industrielle,* (New York: George Brasiller, 1969), p. 14.
[19] Flores, *Arquitectura Española Contemporánea*, p. 90.
[20] Different column shapes are detailed in Archivo Torroja, CEHOPU-CEDEX, '3 - Hotel de El Plantío', ETM-020/Caja 005/04.
[21] Archivo Torroja, CEHOPU-CEDEX, 'Estudio Económico de los Hoteles de El Plantío', ETM-014-caja 004-03_02; Archivo Torroja, CEHOPU-CEDEX, 'Primer Hotel de El Plantío – Cubicaciones', ETM-014/Caja 004/03_01.
[22] Archivo Torroja, CEHOPU-CEDEX, ETM 025-006-02 Original quotes: 'ornamentación sumamente sobria'; 'se ha suprimido totalmente la ornamentación para obtener un tipo de construcción verdaderamente económico inspirándose en el sencillo y agraciado estilo nato de Andalucía.'
[23] Archivo Torroja, CEHOPU-CEDEX, 'Proyecto de Hotel en Sevilla para El Excmo. Señor Conde de Mejorada', ETM-025-002/Caja 006/03_01.
[24] These projects include: a slaughterhouse in Benifairó de Valldigua (with architect Manuel Paucher Ruas) dated 30 March 1929 (Archivo Torroja, CEHOPU-CEDEX, 'Matadero de Benifairó de Valldigua', ETM-031/Caja 007/03. A house in Seville for the Marqués de las Navas dated between July and October 1929, 'Casa para el Marqués de la Nave', ETM-026/Caja 010/02 and 'Casa en Sevilla para el marqués…', ETM-038.001/Caja 008/06 and 'Casa en Sevilla para el marqués..2', ETM-038.003/Caja 008-08. A house in Larachce (Morocco, in collaboration with French architects in Casablanca) dated January 1929, 'Villa en Larache', ETM-38.001/Caja 008/06. A school in Jeréz de la Frontera (with Aguirre) dated July 1929, 'Escuela gratuita en Jerez', ETM-039/Caja 009/01 and 'Proyecto de Escuela Graduala en Jerez…', ETM-039/Caja 009/01_01. Workers' housing in Seville dated August 1930, 'Casas de labor en Sevilla', ETM-058/Caja 013/02. A house in Burgos dated 22 January 1934, 'Casa en Burgos', ETM-113/Caja 030/04.
[25] Fernández Ordoñez (ed.), *La Modernidad en la Obra de Eduardo Torroja*, p. 23. Torroja cited Antoní Gaudí for saying that 'originality is return to the origin.' Eduardo Torroja Miret, *Philosophy of*

Structures, J.J. Polivka and Milos Polivka, trans. (Brekeley: University of California Press, 1958), p. 284. In a 1961 article architectural historian Martin Kermacy connected the 'structural expressionism' of Eduardo Torroja, as well as that of Mario Salvadori, Félix Candela and Pier Luigi Nervi, with Gaudí's work, but the article focuses exclusively on aesthetic comparisons and provides no concrete evidence to directly link these younger designers with Gaudí. Martin Kermacy, 'The Expressionism of Gaudi and Torroja', in Ramon Martinez-Lopez (ed.), *Image of Spain*, (Austin: The University of Texas, 1961), pp. 137-143.

[26] Fernández Ordoñez (ed.), *La Modernidad en la Obra de Eduardo Torroja*, p. 23.

[27] Torroja Miret, *Philosophy of Structures*, p. 199.

[28] Torroja Miret, *Philosophy of Structures*, p. 199.

[29] Torroja Miret, *Philosophy of Structures*, p. 148.

[30] Torroja Miret, *Philosophy of Structures*, p. 198.

[31] Fernández Ordoñez (ed.), *La Modernidad en la Obra de Eduardo Torroja*, p. 80.

[32] Archivo Torroja, CEHOPU-CEDEX, 'ETM-093-001. Gran Mercado de Algeciras: Memoria', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/pdf/planos/158.302.pdf

[33] Torroja Miret, *The Structures of Eduardo Torroja*, p. 23.

[34] Archivo Torroja, CEHOPU-CEDEX, 'ETM-093. Mercado de Algeciras', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/obras/ETM-093.htm.

[35] Torroja Miret, *The Structures of Eduardo Torroja*, p. 24.

[36] Torroja Miret, *Philosophy of Structures*, p. 109.

[37] Torroja Miret, *Philosophy of Structures*, p. 175.

[38] Torroja Miret, *The Structures of Eduardo Torroja*, p. 93; Archivo Torroja, CEHOPU-CEDEX, 'ETM-037 - Muro de contención de Cantarranas en la Ciudad Universitaria de Madrid', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/pdf/obras/ETM-037.pdf.

[39] Archivo Torroja, CEHOPU-CEDEX, 'ETM-037 - Muro de contención de Cantarranas en la Ciudad Universitaria de Madrid', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/pdf/obras/ETM-037.pdf.

[40] Torroja Miret, *The Structures of Eduardo Torroja*, p. 167.

[41] Torroja Miret, *The Structures of Eduardo Torroja*, p. 165.

[42] Torroja Miret, *The Structures of Eduardo Torroja*, p. 34.

[43] Archivo Torroja, CEHOPU-CEDEX, 'La cubierta laminar del Frontón Recoletos', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/img/bibliotecaD/Cubierta_laminar_fronton_recoletos p. 3.

[44] Torroja Miret, *The Structures of Eduardo Torroja*, p. 34.

[45] Torroja Miret, *Philosophy of Structures*, p. 271.

[46] Torroja Miret, *The Structures of Eduardo Torroja*, p. 37.

[47] Archivo Torroja, CEHOPU-CEDEX, 'La cubierta laminar del Frontón Recoletos', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/img/bibliotecaD/Cubierta_laminar_fronton_recoletos p. 2

[48] See drawings of various solutions in Archivo Torroja, CEHOPU-CEDEX, 'Estructura de Tribuna de Preferencia', ETM-115-001/Caja 03/07_02.

[49] Torroja Miret, *The Structures of Eduardo Torroja*, p. 4.

[50] Torroja Miret, *Philosophy of Structures*, p. 187.

[51] Torroja Miret, *The Structures of Eduardo Torroja*, p. 4.

[52] Torroja Miret, *The Structures of Eduardo Torroja*, p. 6.

[53] Torroja Miret, *Philosophy of Structures*, p. 299.

[54] Archivo Torroja, CEHOPU-CEDEX, 'Estructura de Tribuna de Preferencia', ETM-115-001/Caja 03/07_02.

[55] Torroja Miret, *The Structures of Eduardo Torroja*, pp. 14-15. Torroja also noted the Hippodrome's ability to withstand unforeseen forces; sitting on the front lines of combat during the Spanish Civil War, the roof structure endured twenty-six direct artillery hits, yet its structural integrity remained uncompromised.

[56] Torroja Miret, *The Structures of Eduardo Torroja*, pp. 29-30.

[57] Archivo Torroja, CEHOPU-CEDEX, 'ETM-405. Edificio principal de Club Táchira en Caracas (Venezuela)', accessed online on 20 February 2018 at http://www.cehopu.cedex.es/etm/obras/ETM-405.htm.

[58] See first, second and third solutions in Torroja Miret, *The Structures of Eduardo Torroja*, p. 43.

[59] Torroja Miret, *The Structures of Eduardo Torroja*, p. 44.

[60] Torroja Miret, *The Structures of Eduardo Torroja*, p. 46.

[61] 'People', *Architectural Forum*, July (1949), p. 14.

[62] Joseph Siry, 'Wright's Guggenheim Museum and Later Modernist Architecture', in *The Guggenheim: Frank Lloyd Wright and the Making of the Modern Museum*, (New York: Guggenheim Museum, 2009), pp. 39-70.

[63] 'Trebol, 1957-1958', box 1485 folder 12 and box 885 folder 4, Richard and Dion Neutra Papers (Collection 1179). UCLA Library Special Collections, Charles E. Young Research Library, UCLA (hereafter 'UCLA'); Archivo Torroja, CEHOPU-CEDEX, 'Trebol de la Hayda', ETM-410.

[64] Neutra's appreciation for Torroja's work can be seen most clearly in UCLA 0177-48-01, UCLA box 161 folder 147 and 'Building Abroad: Torroja's Sculptural Concrete', *Architectural Forum*, February (1955), pp. 148-50. See also Brett Tippey, 'Collaborative Exchange between Eduardo Torroja and Richard Neutra', paper presented at the 2016 International Conference of the Society of Architectural Historians, Pasadena.

[65] Juan María Songel, *A Conversation with Frei Otto*, (New York: Princeton Architectural press, 2010), p. 20.

[66] See Andrés Cánovas (ed.), *Miguel Fisac: Medalla de Oro de la Arquitectura 1994*, (Madrid: Ministerio del Fomento, 1997).