1. Introduction

Shell structures figure among the most exciting man-built structures. Their attractiveness comes from the expressiveness, efficiency and good structural behaviour they have when properly designed, as shown by the works of Candela [1], Isler [2], Nervi [3] or Torroja [4] in concrete and Dieste [5] in brickwork. In these cases, shells are also very sustainable structures, as they employ small quantities of construction materials, require low maintenance, and have no durability problems (see e.g. [6,7]). However, thin shells are nowadays rarely considered as competitive alternatives for new designs, as pointed out by Meyer and Sheer [8]. According to these authors, the difficulty to properly analyse and design this kind of structure is one of the causes of their loss of popularity. Some books provide a detailed explanation of shell design (see e.g. [9]) and very interesting research is being done in shell optimization and form finding (see [10–12] among others) but analysing the work of the shell master builders is one of the most attractive and inspiring ways to learn about shell design and construction. This idea guided previous works that provided new insights into the roofs built by Candela [13], Tedesco [14] and Dieste [15]. This paper aims to increase the understanding of thin concrete shell construction through the study of one of its masterpieces: the roof designed by Torroja for the Frontón Recoleto in Madrid (Spain).

Eduardo Torroja (1899–1961) is one of the most important structural engineers of the 20th century [16,17]. For almost forty years, he conducted intense activity as university professor, researcher, and consultant engineer [18–20]. He was especially outstanding in the design and construction of thin shell concrete structures, a technical field where his designs provoked enthusiasm due to their audacity, efficiency, and aesthetics [21]. The Algeciras Market Hall (1934), the Zarzuela Hippodrome Roof (1935), and the Frontón Recoleto (1935) are his three major concrete shell projects. To build such remarkable structures, Torroja developed new analysis methods, built scale models, and monitored scale models and real structures to check their safety, learn about their structural behaviour, and improve later designs.

Torroja explained his main works and structural philosophy in his two major books [4,22]. He also explained the details of the analysis and construction of Recoleto’s roof in a report [23] written on the occasion of his appointment as a member of the Real Academia de Ciencias Exactas, Físicas y Naturales (Royal Academy of the Exact, Physical and Natural Sciences). Later works [19,24] have briefly explained the architecture and, qualitatively, the structural behaviour of Recoleto’s roof, but none of them has analysed it exhaustively. This paper bridges this gap and explains the main lessons that can be learned from its design. To reach this goal, the roof is analysed with different FE models of increasing complexity.