The protection against water is one of the most critical subjects in the design and maintenance of any construction. In that sense, the large dimensions of Gothic Cathedrals represent a great technical challenge. Traditionally, the French gothic solves the problem with timber roofs with great inclinations. On the other hand, Meridional gothic uses flat solutions since the climatology and the constructive tradition are different. These flat solutions have water filtrations with time, and most of the temples have suffered several reparations.

The Cathedral of Tortosa is not an exception. Several interventions radically changed the look of the building through years, but the problem of rain water filtrations was not solved. Restorations are documented since XIXth century, and the present paper exposes the last process of restoration of the covering, which took place in the late nineties.

1. INTRODUCTION

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1.1 Chronology

The Cathedral Chapter of Tortosa commissioned in 1346 a new cathedral (Fig. 1) to master Bernat Dalguaire, which had to replace the old Romanesque building. The heptagonal chevet of Tortosa Cathedral were built and covered on first place between 1374 and 1441. It has an apse with double ambulatory arranged on the outside of the old Romanesque Cathedral. The process was documented into "llibres d’obra" (cathedral construction accounts) (11.o.ACTo) (Almuni, 2007). It was built the radial chapels on first place, covered consecutively from the gospel to epistle between 1383 and 1424. The initial section, with a proportion of 9/5, was unusual in late
XIVth century. It is explained because the walls between radial chapels were eliminated (Lluis, 2009). In the second phase, the ambulatory was built between 1424 and 1435. An increasing section and change of construction method takes place at this moment. The proportion of the section changes to 9/6 and the ambulatory vaults are covered symmetrically, over presbytery axis, closing from the mouth to the interior (1432-1434). The third and final phase corresponds to the covering of the presbytery (1435-1441). The main keystone were placed first, and after the vaults were built (Lluis; Almuni, 2011). The temple was consecrated for the first time on April 12, 1441. The fortified citadel concept is evident in the initial design of the gothic cathedral. An example is the battlements of the walls on top of Saint Pedro and Saint Pablo chapels, which will be repeated in all the naves. The flat profile of the covering is finished with lime mortar, as a kind of *opus ceamenticum* (Fig. 2). The first references to the construction of the nave date from 1429, and there is a lack of information until 1440. The construction was developed over several centuries, until the construction of the baroque façade completed in 1757.

![Figure 1. Santa Maria de Tortosa Cathedral (J.M. Roselló, C. Borràs).](image)

2 MATERIAL AND METHOD

In order to establish the restoration criteria, it was necessary to determine the existing constructive layers and also to identify the original constructive solution. Thus, the data obtained through the typological and historical assessment is combined with the physical evidences found in the survey of the covering.

2.1 The covering in Meridional gothic

The new imaging defined in the Council of Trento (1545-1563) imposed a greater importance to the Renaissance city, as a new symbolic reference in the urban space. The new visual reference with inclined roofs attempted to reproduce the imaginary of Constantine times, *laqueada tecta*, Liber I. Chap. V *De tecto* (Borromeo, 1859: 27-29). This aesthetic (and construction typology) flat roof has been assessed as a main characteristic of Meridional Gothic. G.E. Street (1824-1881) highlights the singularity of the flat roof of Barcelona Cathedral (Street 1865: 32). R. Lasteyrie (1849-1921) is strange by the flat roof of southern France cathedrals as a Saint-Nazaire de Carcassone, Beziers or Burdeos. These cathedrals have a cover supported by vaults as in Roman times. E. Viollet-le-Duc (1814-1879) understands the terraces of the cathedrals models in the French Midi (Clermont, Limoges and Narbonne) as an evolutionary characteristic of the Northern Gothic builders (Viollet-le-Duc, 1854-1868, 2: 372-375). V Lamparez (1861-1923) determined the monumental difference...
between Castilla and Aragon. Hall church (hallenkirche) typology and stepwise section of the flat cover (Lamperez 1909, 190 bis Lam.III) were common in the Aragon Crown (Catalunya, Valencia, Aragón).

Josep Puig i Cadafalch (1896-1956) will consider these cathedrals as the origin of the influence of Northern Cathedrals in the Catalan Gothic (Puig i Cadafalch, 1921). Hans Meyer Thesis (1896-1984) assumes the difference between Meridional Gothic and French and English models of cathedral (Sedlmayr 1950). Some authors shaded this concept, as the Catalan Gothic is different to other Meridional models (Bofill, 1977: 39-49). Thus, Meridional Gothic, in a country with a different weather from European, presents two typological characteristics: flat cover and smaller windows (Zaragozá, 2000) (Fig. 5).

From a structural point of view, this cover presents a complex mechanical system, because large weight of concrete is placed over the space. Leopoldo Torres Balbás (1888-1960) checks the structural function ogives and jitters (Torres Balbás, 1939, Torres Balbás, 1945). The roman traditional models gave form to Roman medieval vaults (Basegoda Nonell, 1977: 287-382). Arturo Zaragozá has discussed again the concept of the structural model, proposing that the vault works with the lime mortar coat on top.

Some authors have seen through this constructive system the connection with the Roman building tradition, Bassegoda Amigó (1944), Torres Balbás (1946), Bassegoda Nonell (1977) or Zaragozà Catalán (2008). This configuration of religious buildings evolved towards a model with timber inclined roofs, because of the influence of Instructio in fabricae et suppellectitis ecclesiasticæ libri duo (1577) promoted by Carlo Borromeo (1538-1584), which lead to a formal transformation of the top of the buildings.

2.2 Sample of the roof
A sample (1996) made during the drafting of Master Plan (1995-2000), revealed the original covering of the Cathedral. Juan Bassegoda Nonell (1930-2012) defined this construction system as Catalan gothic vault. This constructive solution can be finished with trespol or ceramic tiles over a flat or inclined surface. It has been used in many buildings along the Aragon Crown, and in the city of Barcelona it has been studied in: Barcelona Cathedral, monastery of Pedralbes, Santa Maria del Mar, Santa Cruz hospital or the church of Santa Maria del Pi (Bassegoda Nonell, 1989a pp. 133-146; Basegoda Nonell, 1989b, 30-38).

This construction technique lightens the weight of the cover, and is usually found in East and South of Iberian Peninsula. It is mentioned in the construction accounts of Barcelona cathedral (Carreras, 1914: 132-133), Mallorca cathedral (Domenge, 1999: 288) or Tortosa (Almuni, 1991:...

Figure 3. Ceramic lightning of Gothic cover (J. Lluis i Guinovart).

Figure 4. Cover section of Tortosa Cathedral (J. Lluis i Guinovart).

3 THE RESTORATION OF THE ROOF OF THE CATHEDRAL OF TORTOSA

3.1 Background

The profile of the covering was changed during XIX\textsuperscript{th} century. In 1800, an architect was called to assess the existing cracks over the sacristy and collateral naves\textsuperscript{1}. The Chapter decided to cover all the naves with an inclined roofing system in 1803\textsuperscript{2}, although the cracks are concentrated only in Catalan-style covers. The new cover will affect the areas finished with “trespol”. The arab-style tiles have a good waterproof behavior, but the new solution caused cracks in the encounters with masonry walls because of the differential thermic expansion of
stone and lime mortar. It is reported in the Cathedral Construction Accounts the repair of water filtrations and cracks in the roof by the master.

So, the first reform of the roof was made with arab-style roofing tiles. The new solution was laid over a timber frame with an inclination of 38.8 %, while in the lateral naves it was built over a rubble infill. The inclination in this case was 8% because the hip line was limited by the high of the windows. It is too small to use arab-style tiles, and caused waterproof problems because of the overlap of the tiles. Thus, the water filtrations caused the saturation of the rubbish infill. Moreover, the new inclined cover sealed the upper ventilation system. These two problems may cause condensations.

Discuss about the cover restoration started in seventies. The Chapter, represented by Mn. Aurelio Querol Lor (1917-1994) asked Juan Bassegoda Nonell (1930-2012) for advice, as he knew the constructive technique and the original section of the gothic cathedral. Joan Bassegoda Nonell advised the inclined cover instead of the traditional Catalan cover solution of flat tile because it has larger expansions and it can generate troubles in vertical masonry walls junction. For this reason, most of the roof of the central nave was replaced (1975). It was previously restored after the Spanish Civil War (1936-1939) by the program *Regiones Devastadas* (1940), but the new timber frame had a different stiffness from previous sections. Then, the critical areas of the lateral naves were not restored.

The problem was not solved, and at nineties, the Generalitat of Catalunya Culture Department commissioned a study about the state of the cover to the architect Alfonso Llorca i Martí, who advised a new intervention recovering the flat roof. The problem became worse after the heavy rains of between 5 and 8 December 1996, during the Pontifical Eucharistic celebration of the Inmaculada Concepción. Thereafter, the Chapter commissioned a study to Josep Lluís i Guinovart, which was sent to the Spanish Ministry of Culture. It ordered an emergency restoration of the cover (1997). The Chapter, chaired by Mon. Manuel Garcia Sancho (1924-2000) resolved the question of the three last decades: they decided to recover the original flat roof.

3.2 The restoration

The emergency restoration was made between 1997 and 1998. The finishing material was not defined in the theoretical flat cover solution. The solution proposed so far was the use of a flat tile covering with a color like the existing arab-style tiles. It is a Catalan Roof System, already
used in the last bays of the nave (1494-c. 1600). On the other hand, the solution with the technique trespol was used in the first stages of the construction, between 1383 and 1494, until the first masonry joint. The solution finally proposed for the restoration uses a finishing with chromatic proprieties similar to the *opus ceamenticium* covering. The solution is an inverted cover, which recovers the initial flatness of the roof, and enables the drainage of rain water below the finishing with artificial stone tiles.

The constructive section has a provisional layer of separation and waterproofing which allows the execution of following stages, protecting the original cathedral cover. Next, a mortar layer will enable the cover to be trafficable. A leveling layer is placed over it, built with low density concrete (200 kp/m³) based on EPS balls, where it is embedded the drainage network of rainwater. Over this cover it was installed the PVC water proof layer with a thickness of 1.5mm, plasticized with polyester fiber armor. This layer completed the provisional waterproofing before the final solution is built.

![Figure 6. Constructive detail of the new solution.](image)

The inverted cover is composed firstly by a waterproofing layer, built with extruded stoneware tiles with natural klinker and low water absorption. Above this layer, it is placed a XPS isolation membrane to avoid expansions, a geotextile layer with a density of 300 kp/m² and finally a 15 cm gravel layer. It will allow the passage of the necessary electrical lines, both indoor and outdoor lighting, as well as water pickups for the maintenance of the covers. The whole passage facilities is made with registrable boxes which allow access to the drainage network of rainwater and its corresponding cover drains, also registrable for maintenance.
Figure 7. Santa María de Tortosa Cathedral Cover (1999).

4 CONCLUSIONS

The assessment of the cover form a historical, typological and physical point of view, revealed the original solution of the masters. Thus, the restoration had the purpose of recovering the original gothic profile of the cathedral of Santa Maria of Tortosa.

The restoration discussed and concluded the main premises postulated by several Chapters and architects during the last thirty years. The constructive solution built can be defined as an update of historic constructive techniques. The lower solution with traditional Catalane-style Cover is used to waterproof, and its upper isolation minimizes the expansions of the material. Moreover, the new solution restores the appearance of the gothic cover. The finishing layer recovers the profile and chromatics of the XIVth century roof, at the same time that the old and new elements are perfectly distinguishable.

ENDNOTES

1 The May 25, 1800 an architect is reported to analyses the Sacristy and Dulce nombre de Jesús chapel, Chapter Archive of Tortosa 1800-1801, (vol.217, fol. 15v).
2 The June 23, 1803 the roofing of cathedral of Tortosa is decided, Chapter Archive of Tortosa 1802-1803, (vol.218, fol. 27r).

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