Following Guastavino’s departure for New York after carrying out his last project in Catalonia (which was precisely his first dome – at the theatre La Massa in Vilassar de Dalt), masonry tile vaults continued to be used here just as they had been in the previous decades as a solution to practical problems in ordinary buildings. Nevertheless, it was not until 1898 that the architect Domènech i Montaner (1850-1923), in his project for the Pere Mata Institute in Reus, became the first to take full advantage of the countless architectural possibilities offered by this vaulting technique, the same one that Guastavino had used earlier that year at the Boston Public Library and in other of his works.

**The Hospital de Sant Pau**

Subsequently to his project in Reus, Domènech i Montaner was commissioned in 1901 to design the new Sant Pau hospital complex (1), an exceptional project in terms of its extension, quality and available funding. The criteria which he adopted both in the complex’s architectural language and in its use of the traditional masonry tile vault were the same as in his Reus project. The general organisation of the complex was based on the hygienist ideas characteristic of 19th-century hospital buildings, an approach which derived from the fact that the purity of the air breathed by patients – which was achieved by assigning a large volume to each one and by a strong ventilation – resulted in decreased mortality and increased recovery rates. This effect was further strengthened by the isolation of the various types of illnesses, grouping the patients in pavilions that were fully separated from one another.

Domènech’s first project for the complex was a big building for the general administration of the hospital and eight pavilions which were based in all cases on a large central hall with a differentiated body at both ends. One of these bodies was conceived to house the so called Day Room, which was laid out on a round plan and had a ceiling topped by a dome with its respective lantern. Without exception, all the horizontal elements of the pavilions were either masonry tile vaults or domes. (2) The thrusts of these elements were counteracted by a complex set of tie rods, ties and portal frames that are hidden from view in the brick masonry of the facades and roofs. (3) The construction process began in 1902.
A new hospital
It proved difficult for the hospital complex to carry out its function since its 19th-century structure was soon surpassed by the new medical procedures. Consequently, in 1990 the health and political authorities, together with the owners of the hospital, concluded that the only solution was to erect a completely new building that would provide all the services that the old pavilions could hardly offer by then. The completed work was not to be inaugurated, however, until 2009, after transferring all the services and vacating the old pavilions.
It was then that the problem affecting almost all our historic architectural heritage was clearly posed: the need to preserve the set of Modernista pavilions, which had been listed by UNESCO as a Heritage of Mankind, meant that they had to be given a new use.
The process is still open at present but three pavilions have already been adopted by international bodies as the headquarters of a delegation of some type. This is the case of the subject of this paper, the Sant Manuel pavilion. It is envisaged that one of the delegations of the United Nations University will be installed there within a few months. To reach this point, however, it has obviously been necessary to carry out an in-depth restoration of the load-bearing structure, vaults, facades and roofs of the pavilion and especially the dome of the Day Room.
The Hospital de Sant Pau Foundation held an open competition for the award of this work, commissioning all the aspects connected with restoration to the group of architects directed by Alberto Casals and José Luis González, professors at the Universitat Politècnica de Catalunya (UPC). Applying a method of their own, the so called objective-systemic method, they succeeded in endowing the old building with a new capacity of use and this paper is based on their experience. (4)

The old Sant Manuel pavilion and its restoration

The Sant Manuel pavilion was conceived for the general surgery of male patients. Domènech i Montaner Jr. took charge of its construction as from 1922.
The pavilion is formed by three bodies: a rectangular central aisle running E-W and two other volumes, one at each end.

[Diagram: Ground floor and cross-section of the Sant Manuel pavilion]
**Load-bearing structures:** The load-bearing structures in the East and West volumes are brick masonry walls and floor systems based on masonry tile vaulting. The facades of the central body envelop a structure of transverse steel portal frames forming 7 bays covered by masonry tile vaults.

**Pere Domènech i Roura on the floor assembly of the type pavilion’s ground floor.** The floor assembly rests on masonry tile vaults supported by IPN beams, which are located precisely under the spring of the steel portal frames that bear the structure of the upper floors.

**Facades:** The facades of the central body have two courses of brick masonry, of 15 cm. per course, forming an air chamber in which the steel portal frames are housed. Cavities are formed in each frame to act as vertical ducts, which are topped by ventilation stacks on the roof. The facades of the bodies at each end of the pavilion have a single course of 1-foot solid brick masonry.

**Roofs:** The roof of the central body has glazed ceramic roof tiles on a tile deck resting on tile jack arches between steel joists. The joists rest on brick masonry arches located on top of the steel portal frames described above. The East and West bodies are covered with roof decks. The West body ends in an apse crowned by a half-dome with cross vaults. It is flanked to the
North by a roof pavilion housing the water tank, topped by a tiny dome, and to the South by the Day Room, covered with the dome that forms the subject of this paper.

Cross-section of the intervention project of the Sant Manuel pavilion

**General restoration**

This project is of purely restorative character since it seeks to give the building back its original character, recovering the values that made it deserving of being listed as a World Heritage Site. Additionally, the building’s net area has been supplemented with two mezzanines that partly occupy the ground floor and the first floor of the central body, providing a total area of 2,657 m².

The Master Plan of 2008 defined the actions required for the complete restoration of the various buildings of the complex. The plan contained a set of documents relating to the Sant Manuel pavilion which were insufficient for a systemic understanding of the building, so several additional preliminary studies were carried out, including test probes to determine the arrangement and state of preservation of the steel structure, flat-jack tests and compressive strength tests to verify the mechanical characteristics of the masonry, the state of degradation and the mineralogical composition of the structural steel, and the vertical steel structure’s working stress.

The most intense work was carried out on the structure. As stated, the brick facades of the central body envelop a structure of transverse steel portals forming 7 bays covered with masonry tile vaulting. Enveloped by the masonry, the central body has some elements that are highly exposed to the weather while others, in contrast, are sufficiently protected since they are inside the building.

Despite the exhaustive study carried out in the design phase, the prospections performed in the course of the works provided a better knowledge of the structure, causing significant changes to be made with respect to the Working Project, which had envisaged the structure’s complete replacement.

It was verified that, despite the visible degradation of the steel, it still had a sufficient cross-section to meet the structural requirements, so it was decided to preserve this structure and carry out a twofold treatment: one structural, based on preventive reinforcements in the nodes, and a durability-based treatment, involving the application of epoxy paints. The basic
assumption is that the rusting speed will follow the normal course of the material's life. The location of the original ventilation system has been maintained in the cavity housed by the structure, although this system has been mechanised in order to filter and climatise the air supply. In view of the complexity of introducing new ventilation ducts into the cavities foreseen for this purpose, it was necessary to design special ducts that optimise the existing cavities to the maximum.

**Restoration of the dome of the Day Room**

Here it is necessary to begin by mentioning the general distrust felt by the management body of the Hospital de Sant Pau with respect to the domes' condition and stability. The collapse of the dome of La Mercè pavilion (which has now been rebuilt) in 2004 lay at the root of this distrust. The dome of the Sant Manuel pavilion, of which the state of preservation had been considered to be of high risk, was fitted with a preventive reinforcement structure in the aim of preventing its possible collapse. The following is a simplified description of the objective-systemic method which was applied to the dome's restoration.

**Stage I. Knowledge**

The dome assembly of the Sant Manuel pavilion is composed in reality of two domes which combine to form an air chamber that is ventilated at the top by a lantern.

- **Top dome**
  - Shape: The shape of the dome is defined by two circumference arches that lend it a pointed profile. It is clad with ceramic “scales” and topped by a round artificial-stone lantern that only provides ventilation. The dome’s cross-section is variable since the thickness is greater in the spring than in the keystone.
  - Material: three thicknesses of ceramic tile with a reinforcement of steel sections. The spring is formed by 7 thicknesses of tile. There is a steel-section tie embedded in the tiles, which is located halfway up the dome. Other sections branch out from it, arranged like “meridians” which are joined at the top by a ring providing support for the lantern above. The lantern, in turn, has 11 vertical sections that support its little columns, and they are closed with another round metal section under the top vault of the lantern.
  - Style: Modernista cladding of glazed scales; ornamental lantern of large dimensions.

- **Bottom dome**
  - Shape: This is a masonry tile vault in the shape of a very flat spherical cap, which springs in parallel to the cap of the top dome, from halfway up the latter, with the assistance of the tie formed by a metal section embedded in the top dome.
  - Material: two thicknesses of tile.
Stage II. Reflection

Assessment
Description of the three types of values found in this element:

- **Instrumental value. Principle of adaptation to use**
  As from its initial conception, the use of the dome has not had, properly speaking, any instrumental value since its function is merely ornamental or, more precisely, semiotic: it is a distinguishing trait of the space that it encloses, a space for the rest and rehabilitation of patients.

- **Significative value. Principle of representation**
  The dome has a great iconic value in the landscape of the grounds, unquestionably associated with a psychological potential of collective identification.

- **Documentary value. Principle of information**
  Likewise, the dome has a great value as a document in all senses of the term: as an element of the material culture of the Modernisme architectural movement and, more specifically, of Catalan Modernisme; as a strictly documentary object; as a witness to a way of building; as a sample of the way in which the turn-of-the-20th-century people related to the public institutions, etc.

Quantification of the magnitude of the intervention

This dome’s constructive fragility, as evidenced by the domes of the other pavilions, would incline one to propose a dismantling and replacement operation. The detailed study of its state of preservation, however, shows that an eminently conservative restoration is possible, above all since the shape and material structure of the dome are as they were originally, not having undergone previous restorative interventions of any significance. Moreover, a positive financial consideration tips the balance in favour of conservation as opposed to replacement.

The dominant criteria should be that the exterior surface (the “scaly skin”) should be restored mimetically, replacing the missing material, and that the structure should be rehabilitated, repaired and protected with paints, adding a preventive structure. The most highly deteriorated elements should be replaced.
Development of project alternatives

The foregoing indicated the suitability of changing the original project proposal, which had envisaged a dismantling and mimetic rebuilding operation: the idea was now to assure the complete conservation of the dome.

Since it is not possible to access all points of the metal sections of the structure, which form an inseparable part of the original building conception, it is necessary to set up a preventive structure, that is to say, a passive structure that would only bear loads in the event of a total or partial collapse.

Stage III. Project performance

Drafting of the project

Considering the collapse of La Mercè dome and the set of existing cracks, a state of alarm inevitably arose, causing the initial project to envisage the dome’s dismantling and subsequent rebuilding.

Performance of the work and drafting of the modified project

Test probes were made to determine the state of degradation of the metal sections, that is to say, of the steel tie (IPN80) and the meridians (T50). The preliminary conclusions were that the sections showed a moderate degree of rusting, as opposed to what had been interpreted in the initial project, so consideration was given to the idea of not carrying out the dismantling operation which the project had proposed for the dome.

In order to carry out the modified proposal, it was necessary to access all the metal sections and nodes, including those of both the lantern and the 4 meridians. This required the dismantling of the bottom dome since it impeded or prevented access to all the sections. On dismantling the bottom dome, a thorough inspection was made of the intrados of the top dome and of the screwed nodes between the tie and the meridians. The pertinent graphic statics studies were carried out by the Wolfe method in order to assure the structural top dome’s stability.
This method began to be applied according to the *steel meridian-free dome* model. In this way it was sought to verify whether the masonry tile shell withstood on its own the weight of the lantern and, consequently, whether or not the steel meridians were necessary. Three hypotheses were considered: 1. The masonry tile shell does not withstand the weight of the lantern; 2. The shell does withstand it, with a direct load entry of the lantern’s weight of 2,584 kg; 3. The shell withstands it, but with a progressive load entry of the lantern; this possibility was modelled, but with a reduction of the lantern’s weight by one half (1,292 kg.). For all these hypotheses it was verified that the tensile forces were produced outside the location of the steel tie, which is in charge of withstanding the parallel tensile forces; that is to say, the masonry tile shell does not withstand on its own the weight of the lantern, so the 4 steel meridians are indispensable. The verification of the load-bearing capacity of the meridians, however, showed that, on applying the 911 kg at 45° of the lantern’s weight on one of them, it absorbs only 679 kg, so the remaining 232 kg should be absorbed by the masonry tile shell that envelops it. Consequently, it is concluded that the steel meridians and the masonry tile shell work jointly, withstanding together the lantern’s weight and the remaining loads.

Having determined that it was not necessary to dismantle the top dome, two fundamental aspects were considered with respect to being able to carry out its restoration on site: the structural safety and the watertightness of the dome assembly.
1. Structural safety

- For safety’s sake, the precautionary steel structure was maintained, using it on the one hand as a working platform and, on the other, as means of support of the lantern.
- In order to extend the durability of the original steel and to assure the original structural nodes, a preventive reinforcement structure based on galvanised steel sections was designed. This reinforcement structure is composed of two trusses, each formed by two T60 sections joined by means of steel bars of 16mm in diameter that were welded to them, and a round steel structure located under the original round structure of the lantern. The trusses are set perpendicularly to each other and parallel to the original meridians, with small contact points formed by movement-limiter plates screwed to the original meridian and the truss. By means of a plate, they are pressed against the waist of the existing masonry, from which the bottom dome sprang and will again be springing. The contact between the new round structure and the original one is made by means of elastic neoprene elements.
- Upon this preventive reinforcement structure, another structure with the same mission was installed on the inside of the lantern. This structure was made by installing uprights that are supported at the bottom and at the top by elastic neoprene elements. The first stretch extends between the original round top structure of the lantern and the original round bottom structure; the second stretch extends between the original round bottom structure and the new round preventive reinforcement structure which forms part of the truss. This assembly assures the structure of the original lantern.

2. Watertightness of the dome assembly

A test was carried out by sprinkling water on the scales that clad the dome. Leaks were observed all along the 4 meridians.
- The solution that was implemented consisted of the injection of a specific waterproofing and sealing mortar, applied from the interior in order to avoid affecting the ceramic scales. It was decided to use a quick-drying mortar of low water content so as not to affect the original metal sections.
- In the restoration of the lantern from the exterior, the water runoff was assured by placing a sheet of zinc between the artificial stone pillars, with a pitch based on the inclination of the top crowning piece of the lantern. Additionally, a bird-protection net was installed on the zinc sheet as a barrier that would protect the interior space between the domes without obstructing the original ventilation.
Once the restoration of the top dome had been completed, the provisional support of the lantern resting on the auxiliary structure could be removed.

All the intervention operations that have been described here were possible thanks to the accessibility achieved by dismantling the bottom dome.

Two possibilities were considered on rebuilding the bottom dome: to rebuild the original dome mimetically or to rebuild it with plasterboard. The discussion on this point arose upon considering Domènech i Montaner’s intention in his design of the assembly and the real function of the bottom dome, which was to close the upper space by way of a dropped ceiling in the Day Room.

As a result of the intervening discussion, the launch of the contractor’s work took place before the final decision had been reached on this matter and the bottom dome began to be rebuilt with plasterboard without the Project Management’s go-ahead. It was determined, however, that the plaster dome was self-supporting and that its spring rested on the existing bulk of masonry on which the original dome was supported, so it was decided to dismantle the precautionary structure. Consequently, the decision was made to maintain the plasterboard closure and to use it as the form, cladding and finish of the new dome, which was built above it mimetically with respect to the original, by means of two courses of tiles. Consequently, the new dome is also self-supporting with a separation of about 10 cm from the plasterboard dome, where a wood-fibre insulation blanket was laid on the plasterboard sheeting.

Likewise, the two bottom domes have one same inspection hatch in the form of an oculus measuring 60 cm in diameter, which allows periodic visual verifications to be made and the performance of maintenance jobs throughout the space between the bottom dome and the top one.


(4) The interior works were directed by Víctor Argentí, architect.