



## Casa da Música, Porto, Portugal

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### INTRODUCTION

“Casa da Música” is one of those jobs in which architecture and engineering are inseparable and strengthen each other. The challenge was to fit a complex functional programme into an object with an atypical form while also ensuring that the support structure should be an integral part of the architect’s spatial concept.

For Rem Koolhaas, the elements which engineering needs are opportunities and themes that give form to the space. Making structural sense, columns and sloping walls are formally worked on and integrated into the project, not by disguising them but sometimes by giving them an unexpected leading role. This process creates an initial conceptual freedom which, through strict formal control, leads to the desired result.



The initial concept was for a translucent building with a metallic structure. Cost reasons and the loss of the transparency effect, which was the inevitable result of the structural elements’ density, led to the choice of white concrete. Although it clearly appealed to Rem Koolhaas, white concrete had not been proposed initially because it is not a common material in Northern European countries where it is difficult to find skilled labour to carry out top quality work in exposed concrete.



The project began in September 1999, following a competition won by the OMA / ARUP joint-venture of which AFAssociados was already a part. The temporary works design project and concrete construction phasing was undertaken in 2001 by AFAssociados.

In terms of structure, in addition to the need to guarantee the overall stability of the building, the following basic concerns are worthy of mention:

- The need to find a set of structural elements, integrated in the architecture, which ensure that the bearing loads are transmitted to the foundations. The geometrical complexity of the building, did not make this an easy task and it was necessary to consider a complicated load path involving making structural use of most of the walls;

- The need to achieve a strict level of detailing to enable the definition of the building's geometry and structural elements, accurately incorporating all the openings and spaces to be used by the installations. As we are dealing with an exposed white concrete building, many of the infrastructure elements are embedded in the concrete and the accuracy of detail is thus also applicable to these installations. The reinforced concrete drawings took on the importance of summary drawings and were changed as the result of successive reiterations between the architects, structural engineers and specialist engineers;
- The establishment of a construction scheduling and a support system compatible with the work deadlines and the contractor's preferences;
- The control of surface cracks given the importance of this feature for the durability of a building made of exposed white concrete;
- The guaranteeing that the work carried out would be of excellent quality by making prototypes to allow the testing of materials and work methodologies and the study of alternative processes and materials together with the contractor.



## GENERAL DESCRIPTION

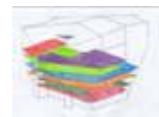
The main structural elements of the auditorium building are the shell formed by the outside reinforced concrete wall panels with 0,40 m thick, and the two large longitudinal walls bounding the main auditorium with 1,0 m thick. This major thickness is due to the fact that there are many open spaces, often large in size, and it is thus important to ensure the walls have the capacity to bear inlaying by other perpendicular structural elements.



Considering the shell and its interior, we find that its centre of gravity is to the south of the geometric centre of its base. This fact, and particularly the increase of this eccentricity due to seismic action, led to the use of two inclined columns to give external support at two points located at the intersection of two of its most southerly edges with the floor of level 0. These pillars pass through the three parking levels and are only visible from there. The unit formed by the external shell, the two internal walls, the two external pillars and the floor slabs which, acting as membranes, work as stiffening vault ribs for the shell, absorbing and transferring the horizontal forces, form the primary structure and stability system of the building.



The external wall panels of the building act as a three dimensional shell with membrane and flexing forces. The behaviour of each panel as a level tension plane contributes decisively to the overall stability of the building. The flexing results from the actions of their own weight and from the actions transmitted by the slabs which are supported on the shell. Sometimes these flexing effects, particularly due to their own weight, would be unacceptable if allowances had not been made for certain auxiliary elements called "interventions". Of note are the two large inclined columns which cross the south and north sides to give support to the roof panels. There are also three columns with circular cross sections coming from the beams and wall of the small auditorium which support the foyer roof above.



Due to the slight slope of the roof panels, certain free edges which were to be very slender would have had excessive deformations unless the reinforced concrete shell had not been replaced by steel structures comprised of open-web girders or beams in a welded, variable cross section

construction. The rigidity of these edges is crucial in those situations where they support the large glass panels.



### NORTH ZONE



The extremely complex geometry of the slabs, stairs, ramps and walls of the North side results in several types of structural solutions for supporting the slab loads. In addition to the main longitudinal north wall and the exterior shell, there are also two lift shafts and an inclined pillar, which also act as vertical support elements. When possible, the slabs are directly supported on the vertical elements or on the exterior shell. In the areas where this is not possible, the slabs are supported on beams or wall-beams which are sometimes also supported by other wall-beams.

### SOUTH ZONE – FOYER



On the South side there is the large volume of the entrance gallery which is interrupted at its upper part by the small auditorium. Between this gallery and the south longitudinal wall of the auditorium there is also a 7 m wide zone for vertical and horizontal circulation and support spaces. This strip is bounded to the South by a 0,35 m thick reinforced concrete wall with a large number of major openings. The vertical supports for the South side slabs, which in the gallery zone are between the foundations and the access stair level to the main auditorium and in the referred circulation zone up to the roof, is provided by the exterior shell, the main South longitudinal wall, the referred 0,35 m thick wall and also the inclined pillar which intersects the gallery space.

At a higher level spanning over the space between the exterior shell and the South longitudinal wall, is the small auditorium. Its main structural elements are two wall-beams 0,45 m thick and variable height. The ceiling and floor layers are composite slabs supported on steel beams.

### MAIN AUDITORIUM



The acoustic isolation of the main auditorium is done by means of separating this from the rest of the structure. This separation is referred to as being a “box within a box”. In this separation the floor, walls and ceiling of the auditorium only come into contact with the building’s structure through resilient mounts.

Each of the two large spaces at the extreme ends of the main auditorium is, for acoustic reasons, made of two glass walls 6,5 m apart. The spaces are 23,2 m wide and approximately 14 m high. The glass walls consist of three stacked panels of “s” curved. The upper two are suspended from the roof while the lower one is supported on the base.

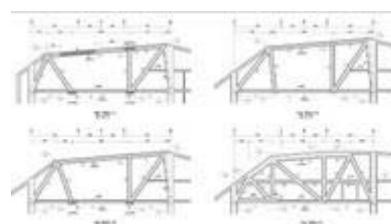
Wind-load resistance is achieved by the wavy glass section spanning between two discreet horizontal trusses, located at the lower and upper thirds of the height, between the two glass planes.

## AUDITORIUM ROOF



The slab above the auditorium (level 8) spans the 24,2 m space between the main longitudinal walls. For this case, two structurally distinct systems were adopted. In the restaurant area, where between the referred layer and the roof there is sufficient height, there is a massive slab supported on the lower flange of steel trusses spaced 6 m apart. These steel trusses go up to the roof and have different geometries dictated by the irregular form of the roof. These trusses also give support to the roof panels of the exterior shell.

In the rest of the area of this floor, composite steel-concrete beams, of built up welded sections with a total height of 1,9 m and 3 m apart from each other have been used, together with a composite steel-concrete slab, 0,20 m thick, with metal sheeting. The beams have opening in their webs to allow the passage of the technical installation pipes.



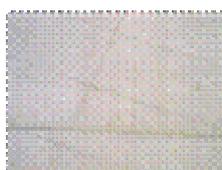
## CAR PARK



The car park layers are massive reinforced concrete slabs. They are supported on isolated pillars, on reinforced concrete walls, on the sloped walls of the auditorium building, and on the peripheral retaining walls.

The columns are circular with truncated conical shear heads and they are generally set out in a 7,8 × 7,8 m<sup>2</sup> grid.

## WHITE CONCRETE



We highlight the fact that we are dealing here with a building made of white concrete which is, to a large extent, exposed. The concrete is simultaneously the structure and the final finishing of the job. This fact makes it particularly important for the structure to function well in practice. Indeed, maintaining the good appearance of exposed white concrete is to a large part done by controlling crack width and by ensuring that forces are correctly quantified.

The correct specification of the concrete is particularly important and great care must be taken in the shuttering and distribution steel work with the job always being kept clean and the workers always concentrating fully on their work.

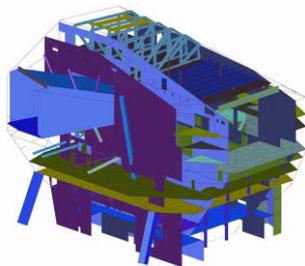


The concrete strength class was C40/50, with a minimum dose of 380 kg/m<sup>3</sup> of 42.5 class white BR I cement, coarse calcareous inert materials, fine calcareous and granite sands and a very fine grained calcareous filler. It is the presence of the granite sand that makes the colour of the concrete slightly greyish and not yellowish as often happens when it is tried to make a concrete as white as possible.

From previous experience it was known that it was normal good practice to remove shuttering very quickly from the white concrete's surfaces to avoid the appearance of marks and blemishes. The impossibility of being able to do this with some panels, due to the complex formwork system, raised the question of the risk of appearance of such marks, naturally undesirable, and it was necessary to make a choice – either the marks should be accepted or an even more sophisticated shuttering system should be used. The timely use of a prototype showed the route to be followed since this indicated that the marks disappeared as the

concrete aged. Several tests were undertaken on parts of the job which confirmed this behaviour and it was thus accepted that the shuttering could be kept on for a greater length of time. Dirt stains and oxidation drip marks, which could not be avoided, were removed by a final cleaning with suitable chemical products chosen after several tests. The entire exterior surface of the concrete is protected with a water-repellent product to avoid the appearance of fungi, a particular risk on the north-facing surfaces.

### CALCULATION OF FORCES AND DETAILING



The overall analysis of the auditorium building was carried out using a three dimensional shell finite element model. The model is comprised of all the elements which form the primary structure.

In addition to being used to determine the forces acting on all the elements due to gravity, thermal, shrinkage, seismic and wind actions, the model was also used to determine displacements and deformations.



### PHASING OF CONSTRUCTION



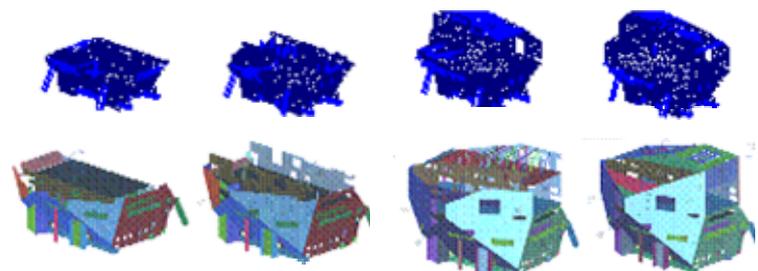
The constructability of the auditorium building of “Casa da Música” was one of the main challenges facing the entire team involved in the project and its construction of “Casa da Música”.

The stability of the sloped walls during construction and the fact that the structure would only be stable as a unit, that is, after the conclusion of the entire exterior shell, required a specific study to be made of the phasing of the construction of the entire structure.

The phasing study carried out thus had the additional objective of minimising the time the shutters remained on the work in order to free up the underlying areas for the carrying out of any necessary following work.

Accordingly, based on the contractor’s initial work plan, which defined the

sequence of concreting foreseen, 88 construction phases were defined for the building and the stability of all these phases was studied individually.



### FOUNDATIONS



In the auditorium building, indirect foundations of piles sunk in slightly altered granite were used. In the car park, footings based in the gravelly layer present at the pillar base level were used.

## CREDITS

*Owner:* Casa da Música / Porto 2001, SA  
*Architect* OMA / Rem Koolhaas  
*Structural design:* Ove Arup & Partners – London / AFAssociados, Projectos de Engenharia, SA – Porto  
*Contractors:* Somague / A.M. Mesquita – Portugal

