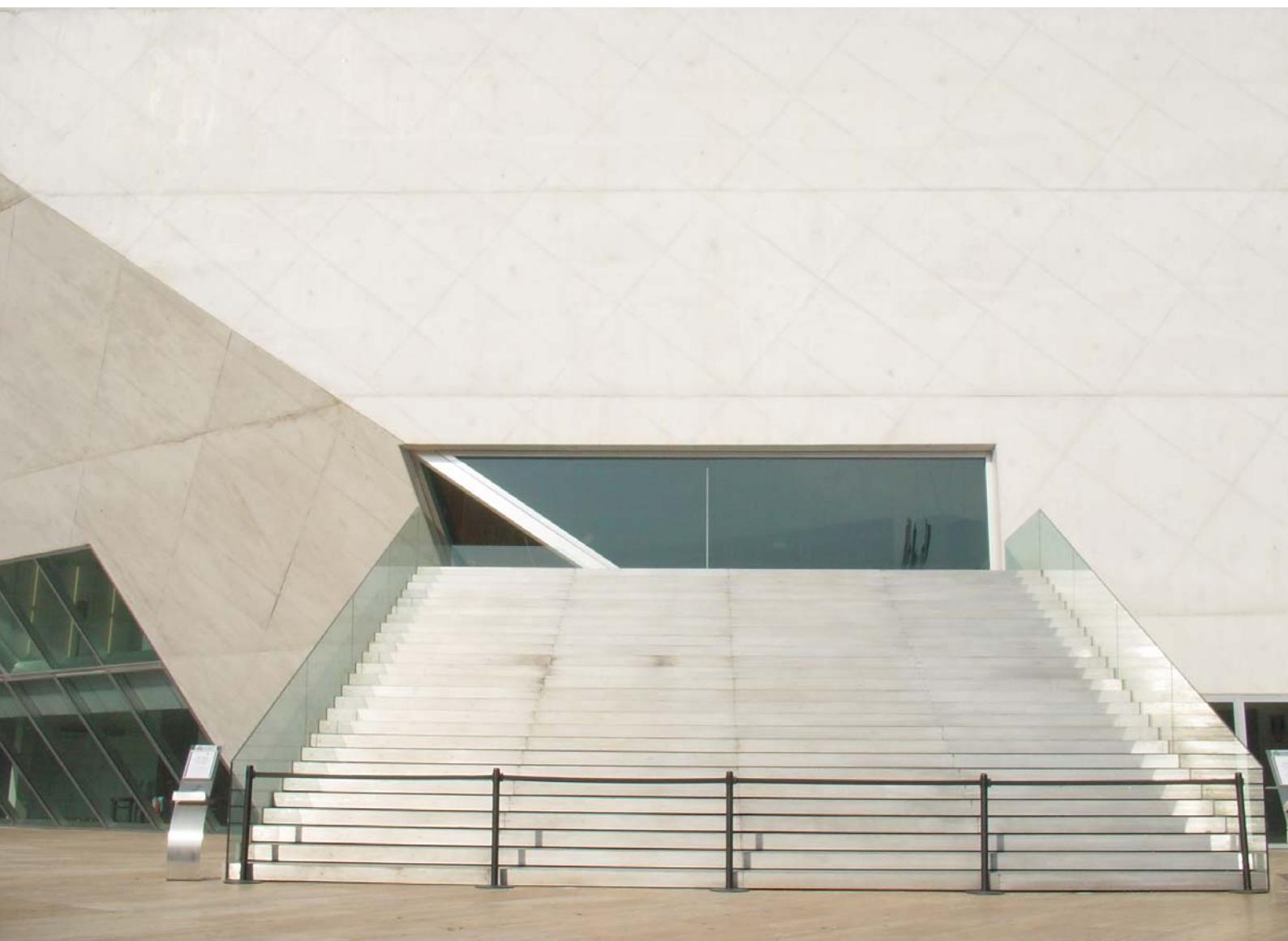


The Engineering of “Casa da Musica”



The Engineering of “Casa da Música”



The “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 Koolhaas, the elements which engineering needs are opportunities and themes that give form to the space. Making structural sense, pillars 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 idea 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 an ideas competition won by the OMA / ARUP consortium of which AFAssociados is a part. The temporary works design project and concrete construction phasing was undertaken in 2001 directly for the construction consortium by AFAssociados, with the backing of the contracting authority.

The Preliminary Study deadline was December 1999. As this was an extremely complex project, in which the technical difficulties inherent in this type of programme (acoustics, environmental treatment) were associated with an unusual geometry and an original structure. It was necessary to mobilise a multi-national, multi-disciplinary team which met weekly in Rotterdam to discuss and agree on the solutions to be developed by the following meeting. The structure, technical zones, piping routes and courtyards were discussed and changed until they were fully integrated into the building.

For the Structural Project a joint team was set up comprising engineers from ARUP and AFAssociados. During the preliminary phase this team worked in London checking the feasibility of the solutions discussed and agreed at the weekly meetings. After the Preliminary Study was delivered in January 2000, the project was developed in Oporto by the same team, where more than 50.000 hours, in AFAssociados only, were necessary to finish the project.

During this period the excavation and peripheral retaining wall contract job was put out to tender by PORTO 2001 outside the context of the contract with the project team. The tender for the structural contract job was scheduled for March 2000 with a view to awarding the work according to price ranking.



Tender bids were indeed called for in March but the awarding of the work as foreseen only happened in August 2000 due to the delay in the excavation and retaining wall contract work and to the inclusion of a third parking level in the project.

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, particularly in the northern zone, 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 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 actual 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 fissures 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.

With regard to the specialist aspects, the mechanical installations were of particular importance since the irregular geometry of the building made it difficult to find routes for large pipes compatible with the architectural requisites and the structural needs. The high acoustic control requirements of the various installations and technical areas were determined by the quality of the systems to be put in place.



Structure

General Description

The main structural elements of the auditorium building are the shell formed by the outside wall panels, made of reinforced concrete, and the two large longitudinal walls bounding the main auditorium. The panels of the outside shell are made of reinforced concrete and are 0.40 m thick. The longitudinal walls are 1m thick, being lightened in certain zones by means of circular vertical voids. 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 pillars to give external support at two points located at the intersection of two of its most southerly edges with the floor of level 0. The 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 some of the floors 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 entire structure is a reinforced concrete monolith. Although, from the point of view of the limiting states of use it would have been desirable sometimes to use pre-stressing, the degree of hyperstaticity and the geometrical complexity of the structure meant that its effects would be very difficult or even impossible to determine.

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 pillars which cross the south and north sides to give support to the roof panels. There are also three pillars with circular cross sections coming from the beams and wall of the small auditorium which support the foyer roof above.



Given 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 substituted by metallic 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 glass panels of the large openings.

North Zone



Given the geometric complexity of the slabs, stairs and ramps of the North side, several types of structural solutions were adopted for supporting the slabs. In addition to the main longitudinal north wall and the exterior shell, there are also two lift shafts and an inclined pillar, which also acts 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. Note that one of the referred lift shafts ends at level 0, being supported in an off-set manner on a rectangular pillar.

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 0.35m thick partition wall with a number of major openings.

The vertical support 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 partition wall and also the inclined pillar which trajectories 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 0.45m thick of variable height. The ceiling and floor layers are made of slabs with composite steel and concrete supported on metal 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. The floor layer is of reinforced concrete, the walls are structural steel, and the ceiling is made of a composite slab supported on



metallic beams. The sizing of the referred mounts was done in such a way that the frequency of the mass – spring – mass system is less than 10 Hz.

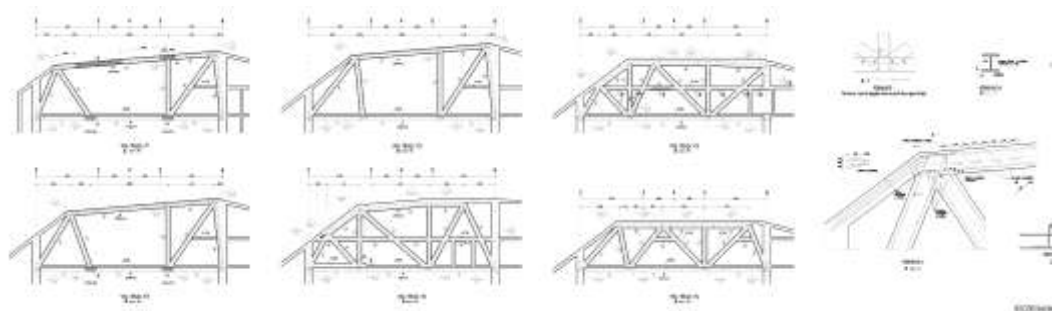
Each of the two large spaces at the extreme ends of the main auditorium is, for acoustic reasons, made of two glass walls 6.5m apart. The spaces are 23.2m wide. The East space is 12.30m high and the West space is 14.70m high. The glass walls consist of three stacked panels of “s” curved. The upper two 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. For horizontal loads, the glass panels hang over the vertical space between open-web girders or between these and the base or the roof.



Auditorium roof

The slab above the auditorium (level 8) spans the 24.2m 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 layer supported on the lower flange of steel trusses spaced 6m apart. These steel trusses go up to the roof and have different geometries dictated by the irregular form of the roof. The beams 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 1.9m and 3m apart from each other have been used, together with a composite steel-concrete layer 0.20m 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 that 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 latter support being done via sliding bolts.

As is the case with the auditorium building, and in spite of being nearly 130m long, the car park structure is monolithic, without joints. However, the two structures are separated by an expansion joint detailed as the car park using steel angles fixed to the auditorium building panels.

The pillars are circular with truncated conical shear heads and they are generally set out in a rectangular 7.8 x 7.8 m² grid. The vertical walls, in addition to being vertical support elements, also act as fire-walls, and sometimes they also act as support for the access ramps.

The underground slabs are generally 0.25m thick while the capitals have a maximum height of 0.50m, including the slab.

As the loads on the roof level are very much greater, these dimensions were increased to 0.35m and 0.7m, respectively.





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 by ensuring the forces at the limit of use 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.

After some research work involving the project team and Secil's technical staff it was possible to define a specification which would enable the obtaining of a concrete with the colour, final finishing, workability and strength characteristics sought.

The concrete was of strength class C40/50, had a minimum dose of 380 kg/m³ of 42.5 class white BR I cement, coarse calcareous inert materials, fine calcareous and granitic sands and a very fine grained calcareous filler. It is the presence of the granitic 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.



Given the special characteristics of this job, notably the concreting of large exterior panels with inclination angles of up to 48° with the horizontal, the contract specifications required the previous construction of several prototypes in white concrete. The purpose of making these large sized prototypes was to acquire knowledge on shuttering methods, protection of the distribution steel, concreting, vibration, the curing and removing of moulds, and to "fine tune" the consistency of the concrete to be used. The various prototypes sought to simulate different exterior panel concreting inclinations, different mould shapes, and vertical and horizontal concrete joints and corners.

It is considered by all parties involved that this learning phase using the "new" material was fundamentally important for the successful use of white concrete on this job.



We should note that the compaction necessary to obtain the finishing and wall effect wanted meant that the white concrete used on the job had strength characteristics close to that of a C50/C60 concrete, much higher than the structural or durability requirements.

Given the nature of this job, notably the concreting of inclined panels, strongly reinforced and shuttered on two faces, at the start of the project (1999) the possibility of using self-compacting concrete was considered. However, at that time there were relatively few references to jobs where this technique had been used successfully and so it was decided not to use it. Later, in 2002, on account of the developments in self-compacting concrete, which had taken place in the meantime throughout the world, it was decided to carry out some tests with a view to using it on some parts of the job. From the tests undertaken it was concluded that the use of self-compacting concrete would require the use of resources, which could not be mobilised at the current state of development of the job, and for this reason the technique was once again abandoned. It would have been necessary to increase the capacity of the pumping plant and the number of lifting units and to alter the shuttering system.



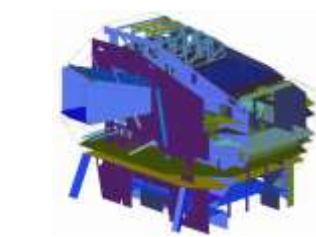
From previous experience it was known that it was normal good practice to remove shuttering very quickly from the white concrete's surfaces to avoid the appearance of marks and blemishes. The impossibility of being able to do this with some panels, due to the complex falsework system, raised the question 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. The lower surfaces of the exposed concrete will also be protected with an anti-graffiti product, which will make it possible to clean off any wall paintings which may be done.



Calculation of forces and sizing

The overall analysis of the auditorium building was carried out using a three dimensional finite element model of the shell.

The model is comprised of all the elements which form the primary structure: the exterior shell, the two main longitudinal walls, the alignment 7 structure, the small auditorium, the inclined exterior and interior pillars, the two stairwells on the north side, the central pillars, the slabs of floors -2, -1, 0, 1, several slabs on the north side, the main access stair to the main auditorium, the layer of level 8, etc.

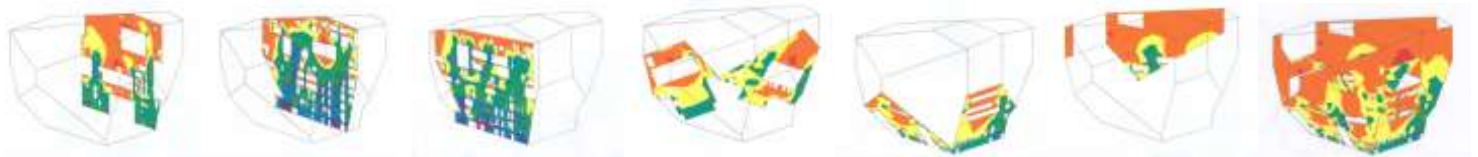
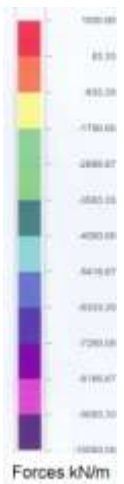


In addition to being used to determine the forces acting on all the elements due to gravity, thermal, theological, seismic and wind actions, the model was also used to determine displacements and deformations.

The need to limit the size of the model to ensure the clear understanding of its structural functioning and to allow the rapid detection of the inevitable modelling errors meant that only those elements which were found to have significant importance in the overall behaviour of the work were considered in the model. The other elements were studied in separate models with different degrees of complexity. The actions transmitted by these other elements to the primary structure were considered in the study of the latter. The slabs included in this model were introduced in a simple manner in order to evaluate the membrane forces in them and the moments transferred by them into the exterior shell. The study of the bending forces in the layers was done in separate, more refined models.



The referred model gave rise to several others, which differ from the former only in the refinement and greater detail of the network of finite elements in certain zones. In this way it was possible to study, for example, the exterior panels considering all their openings, using refined grids in zones with concentrations of forces and considering localised actions not introduced in the "mother" model, while always considering the forces resulting from the overall functioning for all the combinations of forces. As the programme used allows the calculation of distribution steel in reinforced concrete sleeves, the refined models were also used to make an initial study of the distribution steel arrangement.

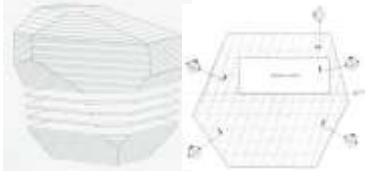


Phasing of Construction and Falsework

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. This would naturally consider the construction sequence foreseen by the contractor as a function of its production resources.

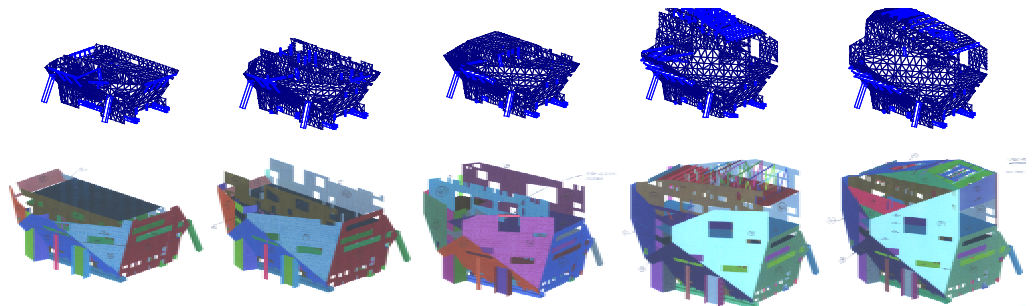


This study was preceded by the contractor defining the type of falsework and shuttering to be used. This in turn was strongly conditioned by the forms defined by the architecture and had to be oblique to the concrete joints. The solution found is shown on the annexed photograph and is based on two structurally independent grids – a main structure, steel and vertical, which supported the secondary structure, wooden and oblique, on which the shuttering panels were supported. This structure made it possible to obtain the form desired, strictly ensuring the continuity of the defined shuttering lines and allowing the disassembly of the lower shuttering levels in order to reduce the time that the shuttering equipment had to remain on the work.



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. Clearly, a “total falsework” solution which would have been in place until the “closure” of the exterior shell of the building would have guaranteed the stability of the building during the entire construction but this would have hindered mobility inside the work and would have made it difficult to meet the deadlines. Such a solution was, therefore, undesirable.

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.



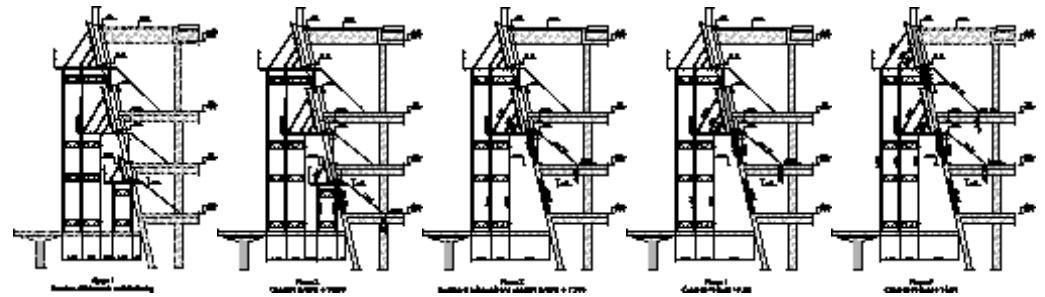
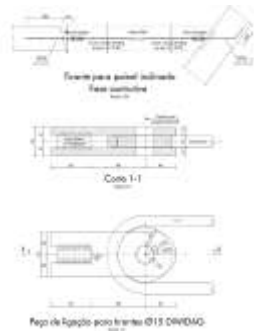
In order to make it possible to disassemble the falsework of the sloped panels during the execution of the horizontal slabs which would give them the necessary tie into the building, provisional tie devices were studied – Diwidag bars anchored in structural elements which had already been completed.



In this study it was necessary to pay particular attention to panel 13 (the most steeply sloping one) and all of the south sector (foyer) on account of the large size of the parts in question and the high number of phases affected by each of them.

During the actual carrying out of the various work phases several adjustments were made to the study of the structure’s stability during construction since it was found that in several situations, due to logistics, the contractor decided to maintain the falsework elements until later phases of the work.





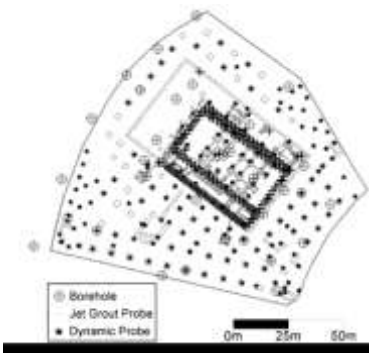
Foundations



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.

Geological – Geo-technical Investigations

The geological – geo-technical investigations carried out consisted of percussion and rotary drilling with SPT tests every 1.5m. These tests were complemented by heavy penetrometer tests of the DPSH type for the direct foundations (car park). In addition, drill holes with destructive drilling were bored in the piling zone to identify the bed-rock level. From the investigations carried out it was concluded that the ground is very heterogeneous with intercalations of hard rock and gravel (rock layers).



Car Park

For the sizing of the direct foundations the ground was zoned in terms of deformability (strength and characteristics of the gravel layer above the rock). A calculation model was used in which the overall behaviour of the gravel layer in response to the localised loads of the footings was considered. The main criterion for sizing was the differential settlement limitation between pillars or neighbouring walls.

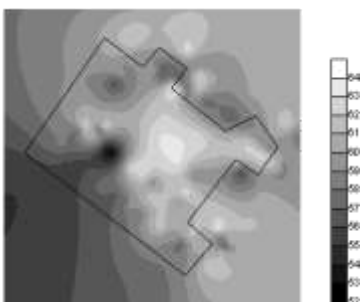
Auditorium building



Ø800 and Ø1300 piles moulded in the ground were used. The holes were stabilised provisionally using bentonite mud. The piles were excavated using a soil auger and / or a rock corer / auger and a bailer (very compact soil and soft rock).

The piles were sized in accordance with the rigid support reactions of the 3D calculation model.

Later, in the case of piles which did not meet the conformity criteria (sonic tests, pile base cores, penetration velocities) these were checked out for use as elastic supports in the structural model, with the capacity for load redistribution of the solid headings and the structure being assessed. The piles were considered as functioning exclusively as point supports.

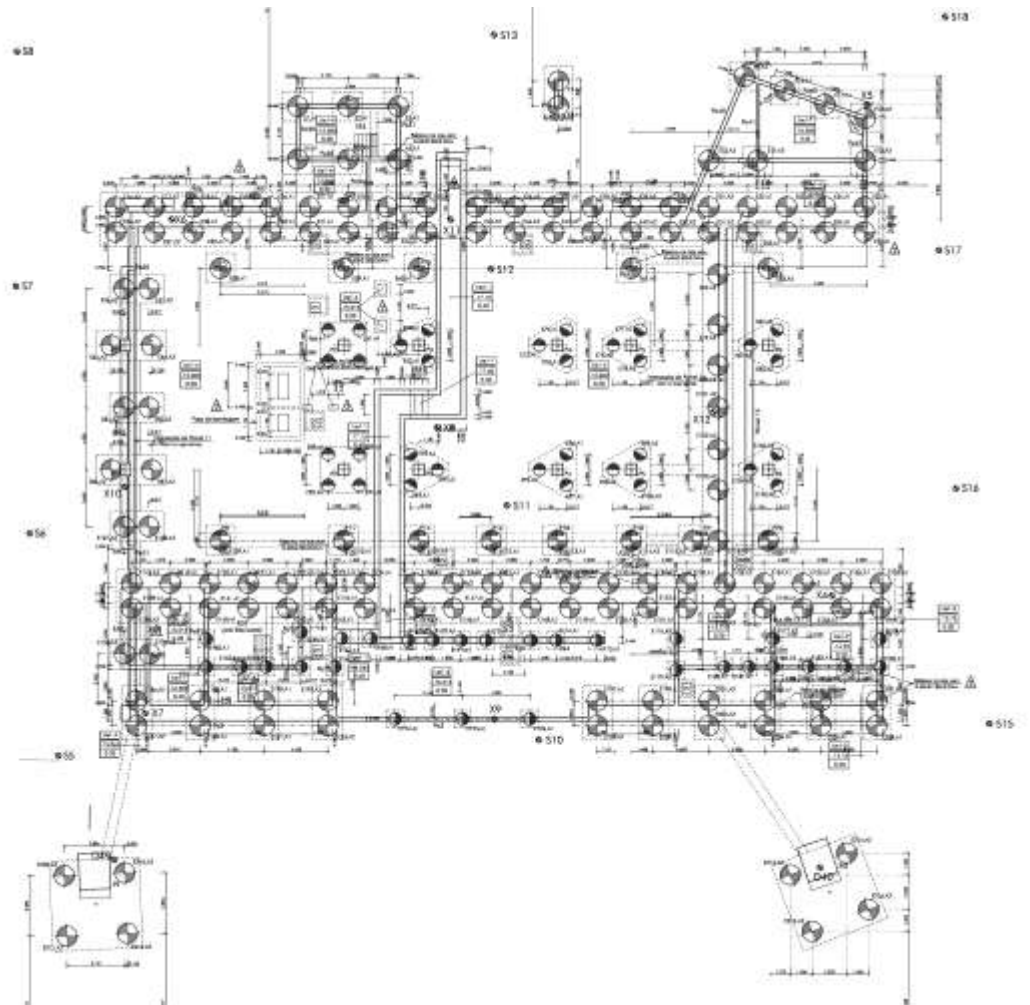


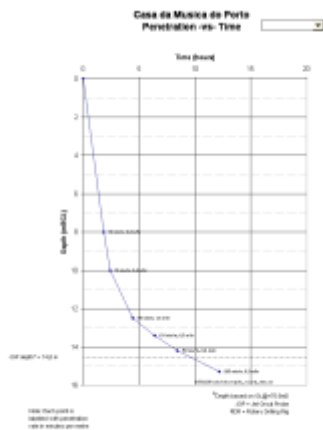


Pile tests

Two pile load tests were carried out. The purpose of the first was to assess the behaviour of the piles under maximum load. (2 x the service load on a Ø800 pile). The second test was aimed at evaluating the pile's in-service behaviour (1.5 x service load on a Ø1300 pile). The results of the load tests confirmed that the piles had been properly built. Note that the load tests were carried out when the job was already underway (they were not prior tests).

Standard sonic tests were also undertaken on all the piles to check the integrity of the concrete in the piles. Cross-hole sonic tests and pile base cores were made to assess the conditions at the foot of the piles bearing most load and those for which the drilling records indicated that there may have been some problems.





Quality control of the piles

In addition to the need to ensure that the pile was sunk in competent ground, it was necessary to take particular care with the conditions at the base of each pile since a “soft” pile base would lead to settling of the pile in question even when this was set in the planned ground. The following measures were taken in this regard:

- Just a short time was allowed between the opening of the hole and the concreting of the pile,
- Tight control of the characteristics of the bentonite mud,
- Bottom of hole cleaning processes.

As already mentioned, for the piles bearing greater loads or for those in which it was suspected there may have been hole bottom contamination (long time between drilling and concreting or inconclusive results of sonic tests), cross-hole sonic tests were done to the base of the pile. If there were still any doubts then cores were taken of the pile basal zone (2m long: 1m in the pile and 1m in the ground). There were piles for which it was necessary to consider a reduced tension – deformation relation and to check the implications on the structural behaviour.

Criterion for stopping drilling for the piles

Due to the loads to be borne and the allowable settling, the piles were based in rock with a W3 degree of alteration (or less) and RQD \geq 50%.

Initially, holes were drilled in the places for each group of piles using a water drilling machine to determine the pile base level (the drilling speed of this machine had been calibrated through the carrying out of previous holes next to the boreholes). However, this equipment was not able to pass through hard layers at shallow depths and the penetration velocities were not also in line with the piling machine penetration velocity and so this method for determining the pile base level was abandoned.

The method which was found to be most reliable for stopping the piles was the analysis of the piling machine penetration velocity. Some additional drill holes were carried out to ensure that we were not basing the pile in a hard layer overlying a soil level.

The criteria adopted for determining the pile base levels were the following:

- Minimum length defined by the geo-technical investigation data and prior drilling,
- Drilling stopped (below minimum length) when penetration velocity was less than 0.50m/h measured for a half-hour period.
- Exceptionally, some piles had lengths less than the minimum due to the “refusal” of the piling machine to advance (penetration generally less than 1m in 2 hours).

Services



The “Casa da Música” represented a challenge in terms of the application of service engineering in a public building. Indeed, this building was considered by the team as a work of art and this was the motivation and justification for approaching the development of the concepts and technical solutions in a special way.

The road to success is not always a straight line and the development of the project became an iterative process based on the architectural advances with the backbone being good, constant communication between the team members. The standard coordination procedures applicable for a normal project were found early on to be inadequate for a building of this nature and it was necessary to provide constant, effective support to the architects in this regard.



The definition of the project assumptions had two distinct components: the client’s needs and the integration with the architecture. The first component was fully explored by working with the client’s representatives, both consultants and operating staff, who clearly expressed and defined in an unambiguous way what they were expecting technically from the building – it was to be the best building of its type in the world.

In the project phase the team subjected the solutions to analysis and calculations using the most rigorous and advanced tools and ensured that they were in full accordance with national and foreign legislation and standards so that the results would be absolutely safe and have little environmental impact.



Electrical Installations

The project for the electrical installations and equipment has a wide range of systems which will enable the building to have solutions which are safe, economically optimised and, above all, integrated with the architecture.

We can highlight the following:

- Power supply and distribution systems;
- Normal and emergency lighting systems and infrastructure for stage lighting;
- Power supply to various items of equipment;
- Telephone infrastructure and structured wiring system;
- Infrastructure for sound and vision distribution and recording systems;



One of the special features of the electrical installations project is the large amount of interaction with several installations, namely: the mechanical, scenery, hydraulic and safety installations. For this reason, communications and coordination between the specialities is critically important in order to ensure that all units are properly integrated.

In general, the technical areas are disseminated throughout the building, thus giving it a significant degree of versatility for a building of this type.



Normal electricity supply to this building will be done through a medium tension grid and the installation of a transformer station made up of two transformers in parallel (2 x 1250 KVA) has thus been planned.

The emergency electricity supply will be used to guarantee the functioning of the essential features of the building. For this purpose it is planned to have a generator unit comprising a diesel motor and alternator with nominal power of 630 KVA. This power source will be used by safety-related equipment in the event of a fire (smoke extractors, water pumps, pressurized systems, lifts and emergency lighting), as well as by the performance-related systems which need to be kept going in the event of a public electricity supply cut.



The building will also have an uninterruptible power supply system (UPS) to guarantee the supply of electricity to IT equipment considered essential for the running of the building. This system will have approximately 30 KVA power.

The distribution of the electricity provided by the referred systems will be done using different platforms based on different degrees of priority for power supply: normal, priority emergency, non-priority emergency and UPS.



As an intrinsic component of the architecture, the technical lighting solutions were given particular attention with technologically advanced systems and sophisticated calculation and analysis methods being used. The architecture included a wide range of lighting and of special interest are those lighting solutions involving polycarbonate and perforated metal sheeting ceilings.



Associated with the technical lighting solutions is the emergency lighting system which, in emergencies, will provide ambient lighting, illumination of the corridors and escape routes and the lighting of the normal and emergency exit signs.

Also interconnected with the lighting systems, but with a specific nature, which was accorded specialist attention, is the scenic illumination system which will enable the "Casa da Música" to use professional systems for the holding of performances of the level being aimed for.

As mentioned earlier, versatility is one of the most valued characteristics in a building of this type. Accordingly, a professional audio and video system has been planned which will enable the recording, broadcasting and projection of professional quality images and sound throughout the entire building, including the outside plaza.



With regard to intruder detection systems, there will be access control systems and an internal and external video surveillance system. It is also planned to have a background music system which can also be used for communications and for making general and emergency public announcements.

The control of all the systems and equipment described will be centralised in a security room through a centralised technical management system which will allow remote control and monitoring.

Mechanical Installations

The “Casa da Música” will have a set of air conditioning solutions which will provide ideal interior air comfort and quality conditions.

The planned systems include:

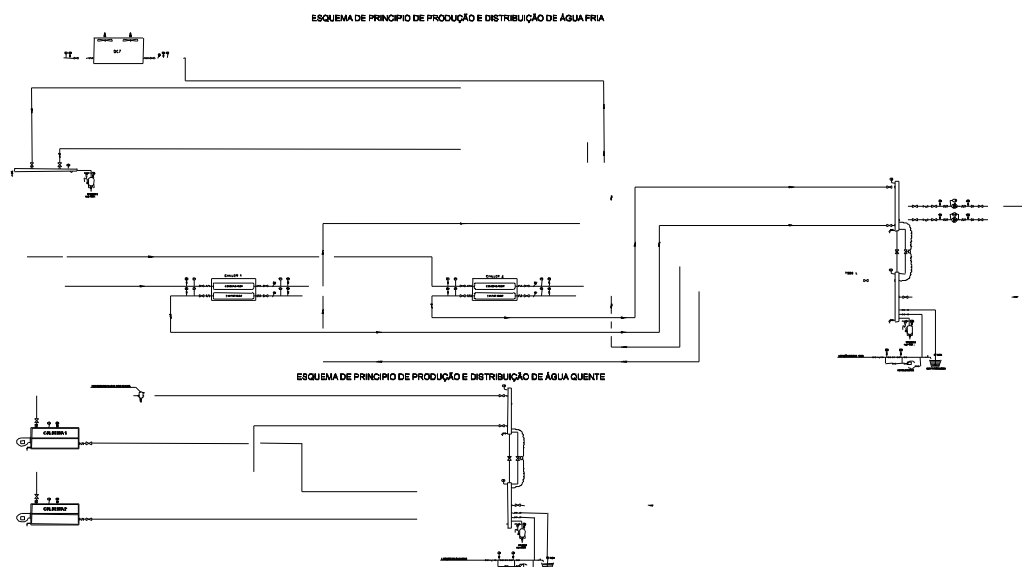
- Systems for producing and distributing chilled and hot water;
- Normal and emergency ventilation systems;
- Environment treatment systems;

The chilled water production system will be made up of two Chillers cooled by air using dry cooler units placed on the outside of the building which will enable the remote cooling of the condensers. The chillers are located in the technical area of Level 3. The chilled water production groups’ power is 2x780 Kw. Their total power is 80% of the maximum expected load considering all the spaces functioning simultaneously.

Hot water production will be done by two gas fired boilers located at Level 9 (top level). The installed heating power is 2x750 Kw.

Hot and cold water distribution will be done by pumps and distribution lines going to each point of use.

The ventilation systems comprise several components, including hygienic ventilation to guarantee good interior air quality, a smoke extraction system and the pressurisation of evacuation routes in emergencies.





The environment treatment systems include a variety of solutions from standard fan coils to a displacement system (Large Auditorium) and heated floors.

The large auditorium is the heart of the entire complex and for this reason all aspects of its design were given special attention.

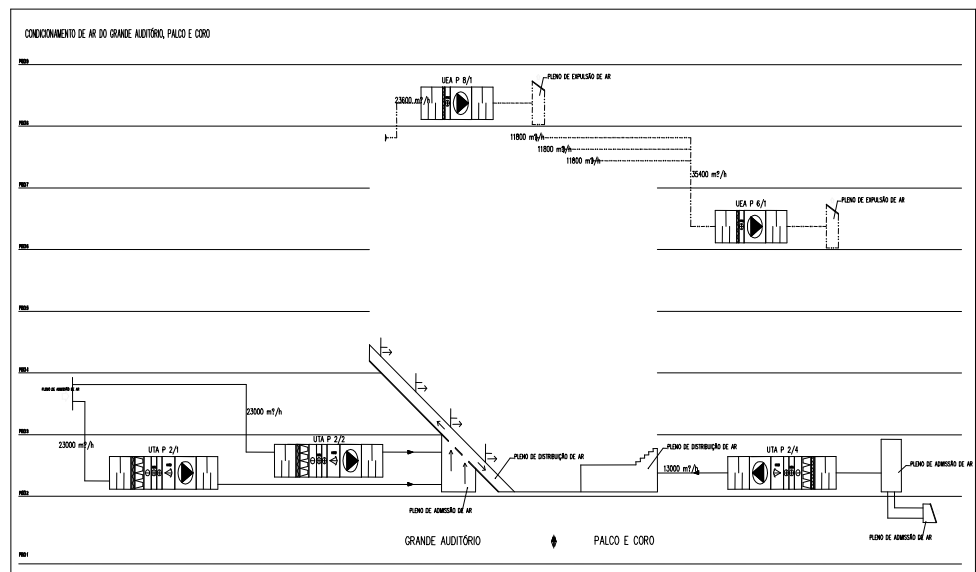
With regard to the mechanical installation, it should be noted that a basic restriction of this locale is that this room must have an NC 15 acoustic index. All features of the installation were sized to respect this requirement.

The environment treatment system planned takes account of the architecture of the locale, in particular the high headroom. Air is blown in near to the occupation zone at low speed and at a temperature close to the desired ambient temperature (Displacement system).

This method of functioning allows substantial energy savings since it reduces significantly the volume of air to treat by taking advantage of the natural layering of the air temperature inside the locale.



The sizing of the systems was based on the intake air flow per person (12 l/s/person) and will always operate with 100% outside air (fresh air).



The environment treatment of most of the spaces will be done by specific air treatment units associated to variable air volume systems. This system will allow individual temperature control for each space and has the advantage comparing to traditional systems of being associated to lower energy consumption systems.

The great challenge faced by the project planners was without doubt the integration of these systems with the architecture in such a way that they were not a limitation but a starting point for bold solutions. This interconnection led to the coexistence of different engineering systems and solutions linked to one of the main present-day worries – the search for high performance energy designs associated with the concern to use low environmental impact technologies.





As an essential design component, the acoustics had an over-riding role in the development of the air-conditioning systems, being considered right from the development of concepts and philosophies. The acoustic requirements imposed tight restrictions and conditioning factors on the systems, resulting in solutions which are compatible with the outstanding performance of the building.

Hydraulic Installations

The hydraulic installations are a central element of the technical installations of the “Casa da Música”. As in a traditional building, the installations comprise the following:

- Water supply network;
- Waste water drainage network;
- Rainwater drainage network;
- Gas network;
- Production of hot sanitary water;
- Protected fire-fighting network;
- Sprinkler network;

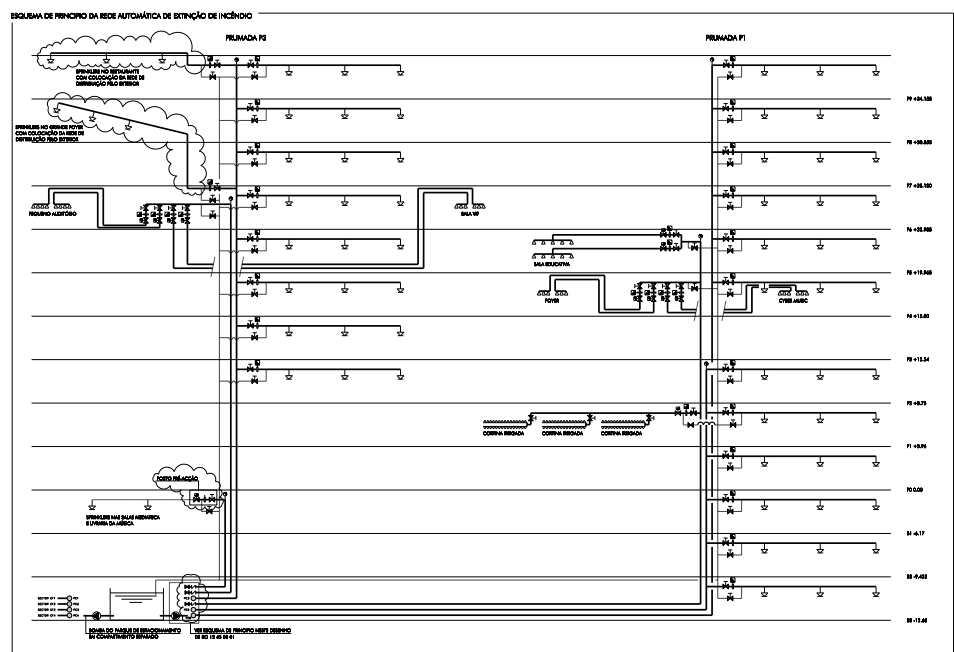


Water supply for the building will come from the public supply system and due to the low dynamic pressure in the area it was necessary to provide the building with reserve and network pressurisation infrastructure. Two different supply routes were considered: one for supplying a fire-fighting water tank and another going to an ordinary water consumption tank. Both are situated on Level 3.



Sizing was done in such a way as to guarantee water supply to the “Casa da Música” for a period of 24 hours in the event of a cut in the public water supply. The useful volume available in the reinforced concrete water tank located on Level 3 is 40 000 litres.

One of the special features of the building is, without doubt, the complete coverage of the inside area by a sprinkler network. This has been possible due to the unique nature of the architecture and provides a level of fire protection which is very unusual for buildings of this nature. The sprinkler system required the installation of a reserve water tank with capacity of 296 000 litres..



Statistics – Auditorium Building

Construction Area	20,136 m ²
White Concrete Volume	17,000 m ³
Grey Concrete Volume	4,000 m ³
Total Area of Exposed Shuttering	27,500 m ²
Total Area of Non-exposed Shuttering	38,000 m ²
Shuttering / Construction Area	3.25 m ² / m ²
Shuttering / m ³ concrete	3.12 m ² / m ³
Steel rods	3,300 ton
Steel rods / Construction Area	164 kg / m ²
Steel rods / m ³ concrete	157 kg / m ³
Construction steel	520 ton

Statistics – Car Park

Construction Area	28,500 m ²
Grey Concrete Volume	14,000 m ³
Total Area of Exposed Shuttering	44,500 m ²
Total Area of Non-exposed Shuttering	9,000 m ²
Shuttering / Construction Area	1.88 m ² / m ²
Shuttering / m ³ concrete	3.82 m ² / m ³
Steel rods	1,700 ton
Steel rods / Construction Area	60 kg / m ²
Steel rods / m ³ concrete	121 kg / m ³



Project Team

An engineering project is always a collective action and the final result depends on the contribution of all the team members.

The “Casa da Música” project which has been underway since September 1999 with a team comprising an average of 14 permanent members (Architects and engineers) is no exception to this rule.

Ove Arup & Partners
London

AFAssociados – Projectos de Engenharia, SA
Oporto

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Hydraulic Installations	Dorothee Richter	Paulo Silva
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Electrical Installations	Dane Green	António José Rodrigues Gomes, Joaquim Viseu (RGA)
Gas Installations		Paulo Silva
Roads and Infrastructures		Estêvão Santana

