A structural description of Lyceu Passos Manuel

Discovery a reality that is our own

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Lyceu Passos Manuel is like a transparent time machine that helps us to see how, by applying our will, it is possible to realize a project, overcoming difficulties and creating the technical conditions so that the essence of the original reality can survive, while at the same time helping to create others.

Just as the original creation of the Lyceu National Central of Lisbon aimed to address a new paradigm of public education, the current intervention also stems from the fairly ambitious intent to recreate school spaces based on regulatory, technical and current education concerns.

When one has the opportunity to work on a building like Lyceu Passos Manuel one becomes aware that our current time is marked historically and is reflected in the architectonic, structural and technological options adopted. In the second half of the 19th century, major civil construction works were planned and implemented, aiming to accompany the transformations that were occurring in other European countries. Technicians arrived from France, scholarship students from the École des Beaux-Arts in Paris, with new technical and architectonic solutions. Among the first was José Luis Monteiro, who began work as an architect in Lisbon City Hall in 1880 and who would be responsible for developing the first design for the Lyceu National Central of Lisbon, which underwent successive alterations and postponements that influenced the final architectonic and structural solutions for the building.

It should be pointed out that the structural form of buildings altered little until the mid 19th century, with systematic use of masonry and wood. Lyceu Passos Manuel, in this aspect, is architecturally rich as it is part of a period of transition, in which new materials and building techniques gradually appeared and overlapped with the more traditional solutions of masonry, stone and wood.

Solutions based on metallic elements, reinforced profiles, flat tiled vaults and perforated bricks were increasingly in general use. Solutions using reinforced concrete came at the end of the 19th century, although these were looked on with great reluctance by many builders of the day.

Note that in 1908 two structural solutions in reinforced concrete were analyzed and compared for the "Gymnasium and Chemistry Laboratory" and for the "Paving and Partition Walls in the Lyceu National Central of Lisbon". These designs were made by the companies Béton de Ciment Armé - Pierre Teissier and Construcções em béton de Cimento Armado, "systema HENNEBIQUE, privilegiado" - Moreira de Sá & Malevez. During the work, these structures were mostly altered in favour of more "current" solutions that used metallic elements, although the reinforced concrete structures were considered to be "fire-proof and tremor-proof, economic and

unalterable". In spite of this, in the work it was possible to detect the existence of two partition walls of reinforced concrete in an excellent state of conservation. The rehabilitation project indicated them to be removed, but given the particular nature of these solutions and their value as heritage of the construction industry the project was changed in order to preserve these elements.

The solutions using metal that were adopted in the Lyceu corresponded to systems that were already very common in other countries, following the Paris exposition of 1878, comprising main girders in iron which supported a secondary framework of iron or wood.

In Line with this highly relevant modernity, this building also has a "classical" or even "archaic" form of construction, with walls of stone masonry founded on a portic structure of arches and masonry wells. It also has a conventual character that is highly structured around the cloisters.

Finally, in January of 1911 the first class was taught in the school now called the Lyceu Passos Manuel, after 32 years of alterations and interruptions.

StructuraL Characterisation of the Lyceu Passos ManueL

The Lyceu Passos Manuel is defined on three levels: one underground which acts Like a cavity; the ground floor, covering the whole of the building Layout area; and the first floor.

The existing structural system has thick masonry walls of brick and stone which support the mixed flooring made up from metallic profiles and flat tiled vaults, on which a filling of concrete made up from measures of sand, Lime and pozzolana was placed. There were also plate girders and angle bars, joined using rivets. According to the bibliography consulted, there were a number of problems in the original construction of the foundation elements of the central building; on the one hand the Land of the foundation did not have the best geotechnical characteristics and, on the other, the water level was very close to the surface, making it necessary to sink shafts for the building’s foundations.

The flooring to the ground floor, according to the design of the original structures and based on data gathered during inspections, mostly comprises a brick vaulted ceiling supported on a metallic framework 0.14 m in height; these beams are supported on main girders.

The main girders used were made up from parallel girders (identified as "type 1" in the said design) or Latticed ("type 2 and 3", idem) and serve to support the floors.

The floor of the first floor is made up from a wood facing, supported on a framework of wooden stays (7x14 cm2i, supported by metal girders, which in turn transmit their Load to the resistant stone masonry walls. The metal girders on this floor are comprised from two types of sections of parallel beams ("type 1" and "type 2"). This solution is used in all wings of the building in the classroom areas. In some cases, there was a superficial Layer made from painted weaker concrete.

In the corridor area adjacent to the patios and in the toilet installations, the structure adopted is characterized by floors/ceilings made from a tiled vaulted ceiling supported on small metal beams, identical to the flooring of the ground floor.

On the roof level, the framework is made up from rafters, binding joists, rods and Laths, except

in the porches where there are only rods and Laths. The binding joists, ridge poles and rods are in U or L -shaped laminated steel profiles. The rods of the porches are formed from L profiles, recessed into the main walls 50 as not to transmit vibration to the arches of the cloister.

The behavior of this type of building, in stone masonry, from the seismic point of view, very much depends on the regularity of its floor Layout and bracing between perpendicular walls. Another very relevant factor is the distribution of the masses over the horizontal and vertical planes. Lyceu Passos Manuel, from this point of view, is quite curious as its distribution of masses and rigidity is very uniform.

The flooring of the ground floor uses a heavier solution, comprising metal profiles and tiled vaults, which is also more rigid, lending it better compatibility between horizontal movements. The basement is semi underground and 50 movement to the ground level is very limited. In terms of the first floor and roof, much Lighter solutions were adopted using mixed structures of steel and wood, along with the use of more reduced plastering.

In terms of Layout, the building is quite compartmented, which helps to provide efficient bracing between the various walls, giving the structure a uniform distribution of horizontal rigidity in all directions. The vertical continuity of most alignments is another relevant factor in terms of its response to horizontal demands.

The design documents consulted did not refer to the seismic factor, which is natural taking into account that only in 1958 was the first Safety Regulation for Constructions against Earthquake published (Decs. 41658 of 31/05/1958) which sets out the differentiation of the earthquake risk in the country quantifying the respective Levels in a simplified manner.

The behavior of these buildings against seismic phenomena was "guaranteed" by good practices and effective building solutions related with the number of floors, the connection between planes of masonry, horizontal disposition of structural elements, connection of the flooring to the façade walls using metal struts and bolts, the adoption of interior walls perpendicular to the façades and well connected to them. Many of these practices were implemented and reinforced in building construction following the 1755 earthquake.

During the 19th century these concerns were being forgotten. The intense process of urbanization at this stage, namely the opening of the Avenidas Novas, Led builders to adopt less sound building solutions: frontal walls were being eliminated, the number of floors was increasing and there were increasingly fewer sections in the diverse structural elements.

Although the Lyceu Passos Manuel had been built in this same period, it did not follow this "philosophy". On the one hand its walls are quite robust and are well founded, while on the other the quality of the materials and respective execution is quite high. The façade walls are 1.10 m thick at basement Level, which is gradually reduce on the way to the upper floors; on the ground floor the width is 0.85 m and on the first floor it is 0.70 m. Frameworks are built into the masonry walls, with some of the alignments being supported by "chains", when Located over the arches of the façades (see detail of the project).

The walls made from concrete and brick also overlap with the masonry walls of the façades. These solutions help to improve the connection between the different materials and thereby

help to improve the building's behavior in terms of building regulations including seismic action.

An analysis of the existing structure, particularly of the resistant masonry walls, was carried out based on the evaluation of the tensions obtained through three dimensional models, according to the recommendations in the Safety and Actions Regulations. Based on these the more vulnerable zones were identified, which were Located in the central body of the building, where the main stairs and the bar are on the ground floor, and the amphitheatre on floor 1. This body was Later studied in isolation simulating the bracing granted by the south and north body through springs.

The central body, from the seismic point of view, has some characteristics which, if they were isolated, would put its stability at risk. As opposed to the zones described above, this zone has little compartmentation and the distribution of its rigidity for horizontal action is unbalanced due to the presence of the body of the amphitheatre on floor 1.

The amphitheatre is bordered by walls of dense stone masonry, supported on metal columns on the ground floor, the rigidity of which is very poor when considering horizontal movement. At the opposite end of this body (central staircase) there is the opposite situation, with high rigidity to the ground floor level. This body depends a great deal on the bracing that is provided by the other bodies of the building.

The Lack of balance observed in the Layouts in terms of rigidity is reflected in the forms of vibration of the structure, which has a component of torsion. Nevertheless, this body is highly influenced by the overall rigidity of the building, which prevents it from having relevant degrees of torsion, which would generate high tension levels in the structural elements further from its centre of rigidity.

The traction tension levels obtained from the three dimensional model are mostly Lower than the safety levels for resistance to traction considered for masonry. Nevertheless, higher traction tensions were obtained in localized zones; taking advantage of the structure's capacity of plastic redistribution of strain, it would be reasonable to admit that a great deal of strain could be transmitted to the elements adjacent to these zones, without compromising the overall stability of the building, only causing a degree of cracking of the masonry in these zones.

An analysis of the structural elements helped us to see that the original design would meet most present day regulatory requirements and that this is largely due to its structural symmetry and to the excellent quality of its construction.

State of Conservation

The process of evaluating its state of conservation was continuous from the design stage up to the conclusion of the works.

In September of 2007, at the prior study stage and based on a number of inspections, it was noted that the building in general showed a good state of conservation, with the exception of localized zones, namely the walls of the south body, next to the body forming the connection between the main building and the block annexed to the laboratories, which displayed quite pronounced cracks, fractures and deformation. During the work stage we were able to see that

this anomaly was associated with broken drain pipes which, over the years, had altered the conditions of the foundation, which were already deficient as they were superficial in this body of transition, as opposed to what was normally the case.

There were also problems associated to infiltrations namely near to humid zones, toilet installations and the terrace, which had caused some elements to come Loose and a generalized separation of components. This was also the case in a large part of the interior facings of the basement.

A degree of cracking was also noted in the interior walls, perpendicular to the façades, associated to the vertical deformation of the metal girders that serve to support them. Some exterior alignments showed signs of the settling of their foundations.

Once the diagnostic study stage was concluded it was considered and confirmed that the intrinsic characteristics of the building and its state of conservation meant that most of the construction could be preserved.

Intervention

The Lyceu Passos Manuel had managed to maintain its structural and constructive coherence for around a century, and so the challenge that arose right from the outset was that of preserving the existing structures and guaranteeing that its behavior would satisfy current regulations and requirements. The introduction of new uses and the specific technical nature of the use currently required of school buildings implied their adaptation and extension.

The project was developed by the architects Victor Mestre and Sofia Aleixo preserving and rehabilitating the existing spaces and allowing for the construction of new buildings, namely the body of the dining hall and the multi-sports facility.

The adaptation of the central body to new uses also implied creating intermediate floors and localized structures mostly related with the creation of accesses, intermediate or mezzanine floors and technical zones.

The Lyceu

In the body of the main building the structural solutions adopted included solutions with a similar function to the existing ones. Mixed flooring was chosen in the intermediate floor introduced in the south wing, with HEB220 metal girders placed 1.5 m apart and a slab with supporting formwork and a total thickness of 0.12 m.

The structure of the musicological centre inserted in the south wing, next to the south-west corner, was realized using a reticulated structure of steel profiles, which supports a wooden framework.

HVAC machines responsible for ventilating the whole building needed to be placed up on the wooden floor. The structure adopted was made up from HEB240 beams and 7x14 cm2 wooden beams placed 0.50 m apart. Access to the intermediate floor and to the wooden floor is gained through a Light structure stairway made of metal and wood, which is part of the existing stairs.

In the work stage it was noted that the existing stairs needed to be reinforced. The original

solution comprised a curious but not very efficient system that included creating an intermediate support in wooden beams through a metal strut. This system did not work very well as the metal strut was not sufficiently rigid to provide the support, which meant that it was necessary to reinforce the stairs by placing metal profiles under the existing wooden structure. Following a fire which happened during the restoration works, it was also necessary to reconstruct the east stairs by using an identical solution to the one adopted in the access to the intermediate floor and to the wooden floor.

In order to facilitate access to the various floors of the building a panoramic Lift was conceived going from the zone of the dining hall up to the access to the intermediate floor. This is a metal structure totally covered in glass, made up from Ll60x160x17 profiles placed in the corners running all of the way up the Lift, braced by tubular RHS120x120x10 profiles set out in the form of a ring; in addition, stainless steel bracing rods with a diameter of 24 mm were also used.

Dining hall - elliptical patio

The dining hall was placed next to the body of the Laboratories and the central building. This structure was placed underground so as not to visually interfere with the existing buildings. This architectonic option was put in place structurally by using reinforced concrete structures based on pre-stressed slabs and bands, supported on walls and/or pillars of reinforced concrete.

The concrete walls are 0.30 m thick and were built against the reinforcement of the masonry walls during the excavation of the earth. The reinforcement solution was proposed by the contractor, HCI, and comprised a 6 m Long stretch of nail work connected to a 7 cm thick sprayed concrete sheet.

In the zones where it was necessary to contain the earth was applied a solution of Munich-style planking with a level of anchoring comprising an alignment of double girders anchored with nail work 14 m Long, placed 3 m apart.

The west zone of the horizontal structure of the exterior ground floor was built by using slabs of reinforced concrete ranging in thickness between 0.20 m and 0.40 m.

In the east zone the structure of the exterior ground floor is pre-stressed and is supported on 0.30 m thick walls and on a reinforced concrete girder which is 1.25 m high by 2.45 m wide, also pre-stressed.

The outdoor awning which covers part of the access area to the dining hall was made from in two sheets of reinforced concrete, connected transversally by girders of variable height and supported on walls of reinforced concrete and on the pre-stressed girder just mentioned.

The design contemplated maintaining the central body but underpinned with metal profiles. This solution was altered due to the difficulties detected during the excavation works, which implied it being dismounted and subsequent reconstructed on a structure of reinforced concrete. During the work stage following the new foundation of the structure it was necessary to allow for the application of a metal structure as a windbreak between the body of the Laboratories and the central body.

With regard to the foundations, given the poor characteristics of the Land, these were built using

micro-piling. The basement floor is made of relatively thin slabs (0.18 m), supported on foundation lintels and on the brackets of the side containment walls. These elements are in turn supported on the indirect foundations mentioned.

With regard to the stairs, three solutions in reinforced concrete were adopted: the stairs of the west zone, with steps marked on both sides, 0.15 m thick; the east stairs, granting access from the interior of the dining hall to the Lyceu, 0.20 m thick, and the outdoor stairs, elliptical in shape, 0.15 m thick.

With regard to the presence of water in the subsoil, the piezometric measurements showed that the water level was of variable depth, but below the level of the foundation; however, there were problems associated to the abundance of water from a pipe that was buried during the execution of the works. In the work stage it was necessary to re-route the pipe lower down, which was performed using a structure of reinforced concrete founded on micro-piling.

Former Pupils Pavilion and Students Association Pavilion - autonomous pavilions

The pavilions for the Former Pupils and the Students Association as well as other localized constructions form part of structures that are complementary to school Life and correspond to smaller scale structures such as access ramps, the housing for the emergency generator group, the Former Pupils Pavilion, the Students Association Pavilion and the structure of the HVAC plant.

The construction of these structures took into account the simplicity of execution of these structures in the Lyceu activities, and 50 reticulated concrete structures and Light structures made from metal and mixed profiles were adopted.

Among these constructions, the main ones are the structures of the Former Pupils and Students Association pavilions based on a reticulated structure with pillars in the form of a cross with the dimensions 150x150x15 (mm), HEB120 profiles for the paving level and HEB100 for the roof, flanked by metal cramp-irons (into which the frames are set). In terms of the floor a slab was placed with supporting formwork with a total thickness of 0.10 m; for the roof 0.10xO.05 (m) wooden beams were used.

Headmaster's house

The first stage of the design of the Headmaster's house contemplated the complete demolition of its interior structure, but this was later reformulated in order to preserve its building characteristics and structural solutions, helping to improve its conditions of use. The floor and roof structures would be maintained and rehabilitated, and reinforced when necessary. In the interior of the building, and in order to grant easier access to the upper floors, a Lift would be created in a metal structure Lined with glass.

The existing structural system in the building of the Headmaster's house is characterized by façade walls in stone masonry. In the central zone of the building there are 2 alignments parallel to the main façade which permit the intermediate support of the wooden beams of the flooring

and of the roof rafters. One of the alignments is made up from a partition wall of wooden boards laid out vertically, joined together through a Lattice-work of wood, while the other is in brick masonry.

The building has two sets of stairs, one of which will be occupied by the Lift structure which will grant easier access to the upper floors. This structure will be supported by RHS120x120xlO profiles braced by galvanized steel struts and faced with glass.

Currently, access to floor O is via the existing stairs and small Landings near to the south façade of the Headmaster's house. These structures have the particular feature of being in reinforced concrete, an example of the "new" materials used in the construction of the Lyceu but which were in a very poor state of conservation, and so they were planned for demolition to be replaced by a metal structure to create a new narrow balcony and metal stairs.

The structure of the narrow balcony will be made from HEBIOO+ profiles all around and GOxGOx7 "T" profiles which support the sheet metal facing; the stairs are a reticulated metal structure of tubular TPS120x6Ox7 and RHS6Ox6Ox3.2 profiles that will also be faced with metal sheeting, above and below, the same as the ones to be found in the connection between the multi-sports facility and the north patio of the Lyceu.

The existing structures have some anomalies that are mostly associated to the presence of water coming from the roof. The project contemplated their repair and the elimination of the causes, namely with regard to wooden elements, which included their careful inspection and the cleaning of the zones affected by fungi and insects. The intervention measures in these cases could include their local reinforcement through lateral binding or by molding with epoxy resin plaster, or in the more serious cases it might be necessary to fully replace them with new frameworks. The existing walls had Loose localized zones and efflorescence associated to the direct action of the rain and infiltrations which implied their reconstruction and the replacement of plasterwork.

This was the way in which it was intended to preserve the Headmaster's house. This will need to be permanently monitored in this second work stage, which is pending.

Mufti-sports facility

The mufti-sports facility was created in the same place as the former games field and comprises one floor which is totally underground (floor -1), a ground floor, which is underground on the side facing north (floor O), and one upper floor (floor 1), which is on the same level as the main patio which accesses the school. This building is intended for sports activities (football, volleyball, basketball, handball, etc.).

On floor -1 there are two covered courts with double ceiling height 7.60 m high, supported by changing rooms and toilet installations in the wing facing south and by a central corridor which separates both sports fields. There are other services and the accesses to the upper floors in this central strip.

The ground floor (floor O) is intended for the public/spectators and the support toilet installations. The entrances to the interior of the building are on this floor, with access to the

Lower floor being either by the Lift or the stairs. The outdoor field on floor 1 is accessed either by exterior stairs or directly through the patio on the north side. Floor 1 is mostly occupied by the main games fields which form the roof of the building. The structural solutions used are based on slabs of solid fungi form reinforced concrete and/or mixed of the steel-concrete type, set on walls of reinforced concrete and/or metal pillars.

In relation to the horizontal structure of the floors, 0.20 m thick solid slabs were used on floor O and on the roofs providing access to the main fields on floor 1. Over the multi-uses hall planned for floor -1, taking into account the clear span of 11.60 m, a solid band was opted for, in reinforced concrete, with a width of 2 m and thickness of 0.40 m. At roof level, given the high spans of 16.40 m of the open-air sports field, a Lighter solution was adopted using mixed steel - concrete waffle slabs, with a maximum thickness of 0.20 m comprising support formwork supported on metal girders of the HEB500 type placed 2.50 m apart.

The design of the multi-sports facility, as in the zone of the dining hall, had to be reformulated due to the same drain pipe mentioned above, which was a major obstacle that needed to be re-routed to go around the outside of the building.

In relation to the vertical structures supporting the flooring, reinforced concrete walls were used with a thickness of 0.15 m and/or 0.20 m. The HEB500 mixed girders of the flooring to floor 1 are supported by tubular metal pillars of the type RHS 200 x 200 x 12.5 mm also set 2.50 m apart. At right angles to the HEB500 girders are metal girders of the type IPE500 which interconnect the various main girders along the alignments of the supports. The whole of the mixed slab of the roof is supported by metal pillars, except on the north side where the mixed slab is set on the retaining wall which supports the earth. For the other roofs which comprise the access to the floor of the outdoor sports field tubular circular metal pillars of the type CHS 152.4 x 10 mm were used.

Retaining walls were used around the whole pavilion, which help to contain the soil up to floor O, except, as already stated, on the north side where the containment of the soil is extended up to the level of floor 1 or rather up to the roof of the multi-sports facility. On the sides facing north, east and west, retaining walls with buttresses were used, due to the higher levels supported. These walls have a vertical wall and buttresses 0.30 m thick and continuous footing. These walls are supported on pairs of piles of 00.40 m and 00.60 m.

In relation to the stairs providing access to the pavilion, stairs with steps marked on both sides were used, in a 0.15 m thick solid slab. Only for the central stairs between floor -1 and O was a solution in metal structure used, formed by three parallel rectangular tubes of the type TPS 120 x 60 x 7.0 mm.

Summary

The structural intervention in the Lyceu Passos Manuel was a highly complex task due to the need, throughout the project, to take the original characteristics of the building into account, which had undergone continuous vicissitudes, like few others, during its design and construction process.

What stands out in this story, and what has to always be taken into account in order to avoid errors and improper decisions from the point of view of the building's heritage, is the excellence of the design and construction procedures adopted. Or rather, the vicissitudes of an extremely lengthy process lasting thirty years did not end up in a poor quality of construction. From this point of view, the Lyceu ended up by being an important source of knowledge and Learning about construction materials and processes that were being forgotten over time and a practical demonstration of what used to be called the art of good construction, in times of few technological resources.

The authors of this structural project now hope that they have been worthy of the task they were commissioned with; what is certain is that they Looked at the structures of the Lyceu in order to understand them and that they have added to this knowledge, where possible, and in their deeds demonstrated the respect that the structures deserve, both when making alterations, and when new structures were designed for new functionalities, and overall seeking the harmony and the quality that this historic building justifies and deserves.